Biologic and Economic Assessment of Benefits from Use of Phenoxy Herbicides in the United States

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EXECUTIVE SUMMARY

Rationale

We are entering an era in the United States where all pesticides registered prior to November 1984 must, by law, either be re-registered by 1997 (recently extended to 2001 with passage of the Food Quality Protection Act of 1996) or their use discontinued. This legislation may result in the cancellation of nearly half of all our pesticides. The first phenoxy herbicide registered was 2,4-D in 1945, and registration of other herbicides in this chemical family followed shortly thereafter. There has been worldwide acceptance and widespread use of the phenoxy herbicides since their introduction. They still represent the most widely used family of herbicides in the world; so it behooves us, to make a concerted effort, to retain humankind's use of the phenoxy herbicides by quantifying their biologic and economic benefits. More effective weed control has been a major factor in increasing crop yields in developed countries worldwide since the introduction of 2,4-D and subsequent selective herbicides.

The phenoxy herbicides were so effective and economical for selectively controlling broadleaf weeds in grass crops that they put selective weed control in the "public spotlight" worldwide. Also, 2,4-D launched accelerated weed management by the use of herbicides in the emerging discipline of weed science. Phenoxy herbicides have provided very economical, selective, postemergence control of broadleaf weeds in grass crops and non-cropland for the past five decades. The first widely used organic herbicide developed was 2,4-D, and it is still the most widely used herbicide throughout the world.

Today, phenoxy herbicides play a major role in weed management when used either alone or in combination with other herbicides because they economically enhance the weed control spectrum of many herbicides. The herbicide 2,4-D is registered (tolerances have been established) for use on over 65 crops in the United States, and other phenoxy herbicides are registered on over 25 crops. Also, the phenoxy herbicides are registered for numerous non-cropland uses.

This biological and economical benefits assessment of phenoxy herbicides encompasses all the cropland and non-cropland uses in the United States. Concurrent toxicological studies of 2,4-D have been conducted by an Industry Risk Assessment Task Force, and all studies required for re-registration were completed and submitted to the Environmental Protection Agency (EPA) in December 1995. Thus, this benefits assessment of the phenoxy herbicides provides additional supportive information for the re-registration process.

Objectives

The major objective of this assessment was to determine the biologic and economic benefits from the use of the phenoxy herbicides in the United States. Specific objectives of the study were to review epidemiology and toxicology data of phenoxy herbicides, and determine their use rates, timing of applications, acres treated, and total pounds of acid equivalent utilized on cropland and non-cropland in the United States. Estimates were made in each state, plus

Puerto Rico, of alternative herbicides or non-chemical weed control methods, availability of alternative methods, use and costs of alternative methods, and crop yield impact with alternative methods if either 2,4-D or all phenoxy herbicides were banned. Thus, estimates were made of the net societal effect (production plus consumer costs) of banning either 2,4-D or all phenoxy herbicides in the United States. Individual authors also listed the various impacts of banning either 2,4-D or all phenoxy herbicides that are not readily amenable to an economic cost estimate, but are important for managing weeds on cropland and non-cropland.

Methodology

This assessment was conducted by selecting a Task Force of seven public weed scientists plus an epidemiologist, toxicologist, and economist; developing a generic questionnaire for all phenoxy herbicide uses in the United States; and selecting weed scientists in each state to provide the use and benefit information. State weed scientists used state and federal grower surveys plus any other data available to respond to our questionnaires. Common sources of information included publications for federal and state agencies, data from industry, grower and agri-business surveys, and journal articles from referred and non-referred sources. Questionnaires were mailed in early 1993 to gather information about phenoxy herbicide use during 1992. Thus, the information received relates mainly to the 1992 growing season, but it is representative of subsequent years because many of the uses of the phenoxy herbicides have stabilized. An exception would be the increased use of 2,4-D preplant for no-till soybean production since 1992. The quantity of the various phenoxy herbicides used was from state surveys and independent estimates, and total use compared favorably with national sales data from basic producers of these phenoxy herbicides. The potential alternative weed management methods (both chemical and non-chemical) to the phenoxy herbicides were provided by the selected weed scientist or other scientists best able to provide that information for the state in question. Quantification of the economic impacts of banning either 2,4-D or all phenoxy herbicides was made using published suggested retail prices of herbicides, estimated costs of tillage and other production practices, reported application and labor costs, estimated yield losses with alternative weed management methods, and reported commodity prices in the world; so it behooves us, to make a concerted effort, to retain humankind's use of the phenoxy herbicides by quantifying their biologic and economic benefits. More effective weed control has been a major factor in increasing crop yields in developed countries worldwide since the introduction of 2,4-D and subsequent selective herbicides.

Results

Authors of this assessment discussed the use of phenoxy herbicides in over 65 crops and numerous non-cropland uses. Usage of all phenoxy herbicides in the United States was estimated at 55 million pounds of acid equivalent (47 million pounds of just 2,4-D) with a retail sales value of $171 million during 1992.

The estimated net societal loss from banning only 2,4-D in the United States would be $1.683 billion; whereas, banning all phenoxy herbicides would result in a loss of $2.559 billion annually (Table 1). Approximately 37% of this net societal loss represents increased weed management costs from the use of more expensive alternative herbicides or non-chemical weed control methods. An additional 36% of the aggregate loss occurs because of decreased crop yields. The remaining 27% is considered a net societal loss for consumers because of higher retail commodity prices. Decreased crop yields occur to a greater degree with the minor acreage crops where alternative herbicide choices are more limited than with the major acreage crops.

Discussion

Loss of the phenoxy herbicides in the United States would markedly reduce our ability to manage broadleaf weeds in over 65 crops and in numerous non-cropland situations. In those situations where weeds are manageable without the phenoxy herbicides, weed control costs would increase markedly because alternative herbicides and non-chemical methods are much more expensive or more labor intensive than the phenoxy herbicides. Presently, 2,4-D is one of the lowest cost herbicides for broadleaf weed control in the United States, and thus it tends to keep the retail price of substitute herbicides competitive. For example, in Minnesota (Cultural and Chemical Weed Control in Field Crops 1996) the median suggested rate of 2,4-D amine at 0.5 lb/A for broadleaf weed control in spring wheat would cost $1.59/A, non-phenoxy herbicides suggested for broadleaf weed control at their median rate averaged $5.05/A, and suggested herbicides for grass (wild oat) control in spring wheat averaged $15.58/A. Thus, 2,4-D may be partially responsible for the reduced price of other broadleaf herbicides in contrast to the higher price of grass herbicides in these same small grains. Also, the only broadleaf herbicide registered on some minor crops (e.g., almond, blueberry, cranberry, grape, nectarine, pear, strawberry, and wild rice) is 2,4-D, and its loss would adversely affect the production of these crops.

In addition to the need of 2,4-D as a herbicide, it is also important as a plant growth regulator. Navel orange and grapefruit growers in Arizona and California use 2,4-D to stop abscission layer formation in the stems of citrus fruit. Thus, they use 7,600 pounds of 2,4-D at a total chemical cost of $24,170 which will delay fruit drop up to 2 1/2 months. If these citrus fruits could not be "stored" on the trees (dropped fruit are lost), there would be an estimated annual loss to growers of $80 million.

Conclusions

Cancellation of all uses of phenoxy herbicides in the United States would have widespread impacts; a few of these concerns are listed below:

- The net societal loss (production plus consumer costs) of banning the phenoxy herbicides would be $2.559 billion annually.
- Farmers would suffer an annual loss of $1.868 billion because of yield loss and increased weed control costs in over 65 crops and in many non-cropland situations.
- Industry would lose $171 million in annual retail sales of phenoxy herbicides, but could compete for the new market created for alternative herbicides worth $914 million.
- Human injuries may increase as farmers shift to greater use of mechanical weed management methods.

- Controlling the development of herbicide resistance in weeds would be more difficult because the phenoxy herbicides have shown little potential for development of weed resistance, and they are widely used with other herbicides to expand the weed control spectrum.
- Phenoxy herbicides are widely used to control plants poisonous to livestock and humans as well as many weeds that cause human discomfort (e.g., hay fever from ragweed pollen to allergic reactions from poison ivy).
- Economically effective herbicides would be lost for many crop production situations, and for numerous non-cropland uses (e.g., lawn weed control to brush control under transmission lines).
- Phenoxy herbicides have been used for 51 years with little or no acute or chronic toxicity to humans. Based on extensive animal and human studies, phenoxy herbicides are not likely to cause cancer. Typically, the general public is not exposed to unsafe levels of the phenoxy herbicides. Switching to alternative herbicides does not guarantee increased safety to human health as compared to the enviable human safety record achieved with the phenoxy herbicides.
- The general public would have to accept a decline in the aesthetic value and playability in areas ranging from lawns and parks to golf courses.
- Control of aquatic weeds would decline and the general public would recognize this in activities ranging from swimming to navigation of waterways.
- The net societal loss if 2,4-D were banned would be $139 million annually for peanut production alone, and the return to Southeastern United States peanut growers would decrease by $138/A.
- Preplant use of phenoxy herbicides has become increasingly important because of increases in no-till soybean production during the past few years and 2,4-D remains a mainstay in most other no-till crop production systems.
- Minor crops would suffer more production loss per acre from a phenoxy herbicide ban than major crops because these low-acreage, high-value crops do not often justify the cost of registering alternative herbicides.
- Loss of phenoxy herbicides would necessitate increased tillage and thus accelerate soil erosion and water pollution at a time when government programs and farmers are striving to reduce tillage to conserve soil and energy and improve water quality.
- The management of over 100 weeds, classified by law as noxious, would be much more difficult without phenoxy herbicides and the annual net societal loss would be $180 million.
- The general public would be impacted in areas ranging from increased consumer costs for many foods totaling $691 million annually to higher lawn and turfgrass management costs.
- The phenoxy herbicides have greatly aided humankind by increasing worldwide food production and reducing the drudgery of weed management while generating an outstanding record of human and environmental safety.

Table 1. Estimated 1992 net societal loss (production plus consumer costs) from banning either 2,4-D or all phenoxy herbicides in the United States.

Area	Banning 2,4-D	Banning all phenoxy herbicides
	------------------------- Millions of dollars -------------------------	
Pastureland	383	384
Field corn	246	246
Turfgrass	232	367
Noxious weeds	162	180
Small grains	148	284
Fallow	125	125
Orchards & vineyards	111	111
Rangeland	80	81
Other field crops	65	75
Soybean	35	155
Sorghum	31	31
Rights-of-way	19	19
Forestland	17	18
Aquatic sites	17	17
Vegetables	12	12
Alfalfa	0	315
Peanut	0	139
Total	**$1,683**	**$2,559**

Chapter 1

Rationale for the Phenoxy Herbicide Benefits Assessment

ORVIN C. BURNSIDE[1]

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WHY THE ASSESSMENT WAS UNDERTAKEN

During the past several years a National Agricultural Pesticide Impact Assessment Program (NAPIAP) Task Force has conducted a biologic and economic assessment of benefits from the use of phenoxy herbicides in the United States. Phenoxy herbicides, such as 2,4-D, have provided economical, selective, postemergence control of broadleaf weeds in grass crops and noncropland for the past five decades (8, 12, 13). A major use of 2,4-D today is in combination with other herbicides because it economically enhances the weed control spectrum of many herbicide mixtures. The herbicide 2,4-D is registered for use on 65 crops in the United States and other phenoxy herbicides are registered on 25 crops, and these herbicides also have numerous noncropland uses. The chemical, 2,4-D, was first registered with the United States Patent Office for use as a herbicide in 1945 (12). Like other pesticides registered prior to November 1984, the phenoxy herbicides must be re-registered with the Environmental Protection Agency (EPA) by 1997 or all present registrations will be lost.

This benefits assessment of 2,4-D and other phenoxy herbicides encompasses all their cropland and noncropland uses in the United States, along with their biologic and economic benefits. This report will provide EPA personnel and others with benefits information about the phenoxy herbicides that will be useful in deciding whether this class of herbicides should be re-registered. Also, we are presenting a historical account of the development of phenoxy herbicides in the United States, and the impact that these herbicides have had on weed management technology and the development of the discipline of weed science.

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ENVIRONMENTAL AND TOXICOLOGICAL INFORMATION

Environmental concerns and risk data development for 2,4-D re-registration was completed by the Industry Risk Assessment Task Force II in time to meet the December 1995 EPA deadline. Other Industry Task Forces have conducted risk research, as specified by EPA, for re-registration of other phenoxy herbicides used in the United States. A synopsis of environmental and toxicology information with the phenoxy herbicides is presented here, but in Chapter 3, epidemiological and toxicological information is presented in greater detail.

Based on dissipation studies, the acid, salt, and ester formulations of 2,4-D readily break down in the soil with an average half-life of 4 to 10 days (1). The herbicide 2,4-D can persist in detectable amounts in the environment for 1 to 4 weeks after application. Movement in soil is usually less than 6 inches downward from the site of application. In sandy soils with low organic matter content in California, 2,4-D has leached only 12 to 18 inches even after large amounts of water were applied (1). Thus, groundwater contamination with 2,4-D across the United States has remained very low (2), and new phenoxy herbicide management practices should further decrease the potential for groundwater contamination (4). Phenoxy herbicides decompose primarily by microbial activity, and degradation increases with increased soil pH, moisture, organic matter, and temperature. Little genetically based weed resistance development has been observed despite the extensive use of the phenoxy herbicides during the past five decades (7).

Dissipation of 2,4-D is rapid in surface water and trace amounts are only occasionally detected (2), even though some ester and salt formulations of 2,4-D are registered and used to control aquatic weeds in lakes and ponds. The Health Advisory Level for 2,4-D that was established by EPA for potable water is 70 ppb (3). EPA has rated 2,4-D as "practically nontoxic" for both warm water and cold water fish, and monitoring studies indicate no evidence of bioaccumulation in fish or the environment (1). EPA has classified 2,4-D's bird-dietary-toxicity and honeybee-toxicity as "practically nontoxic" (1). Because there is little residue from phenoxy herbicides in the air, soil, or water and because residues in treated vegetation decline rapidly, exposure of wildlife to phenoxy herbicides has been low. The major effect phenoxy herbicides have on wildlife is habitat modification, because of reduction of broadleaf vegetation, but these effects may even be beneficial to wildlife (6).

The phenoxy herbicides are low in toxicity to humans and animals (1, 9). No scientifically documented human health risks, either acute or chronic, exist from the approved uses of the phenoxy herbicides. Acute toxicity to humans, based on oral, dermal, ocular, or inhalation administration, may vary with the 2,4-D formulation. However, phenoxy herbicides have been used widely by numerous individuals (9) from home owners to farmers and ranchers, and even with significant exposure, humans have shown essentially no acute toxicity (11).

In the late 1970's and the 1980's, questions were raised about the chronic effects to humans from repeated exposure to the phenoxy herbicides because of the occurrence of three rare forms of cancer (10). A comprehensive study of the scientific evidence relating to the safety of 2,4-D was published in 1992 (11). This report stated that: "The case-control epidemiological studies that have been the source of the cancer risk hypothesis are inconclusive. Problems in assessing exposure based on patients' memories make these studies difficult to interpret. Cohort studies of 2,4-D-exposed workers do not generally support the specific hypothesis that 2,4-D causes cancer. Taken together, the epidemiological studies provide, at best, only weak evidence of an association between 2,4-D and the risk of cancer." The report further states: "Historical exposures to 2,4-D by user groups, particularly farmers, forestry workers and commercial applicators, would be higher than those sustained under present rigorous standards for application which involve the use of protective clothing and other measures to reduce exposure. Proposed label changes indicate that in the future exposures will be even further reduced. Viewed in this context, the available data indicate that the potential public health impact of 2,4-D, including the risk of human cancer, was negligible in the past and would be expected to be even smaller in the present and future."

Another Advisory Panel convened by the EPA to evaluate toxicology studies on 2,4-D since the prior report in 1992 (5) stated: "The Committee concludes that the data are not sufficient to find that there is a cause and effect relationship between the exposure to 2,4-D and NHL (non-Hodgkins lymphoma)." Thus, the risk to humans from exposure to the phenoxy herbicides has been considered negligible. Therefore, a benefits assessment of the phenoxy herbicides in the United States, which is the objective of this report, would be very useful considering the limited evidence of any apparent adverse human health or environmental risks from the use of these herbicides.

HOW THE ASSESSMENT WAS CONDUCTED

An organizational meeting on November 4, 1992 was attended by Orvin Burnside, Ronald Davis, Leonard Gianessi, Dennis Kopp, Craig Osteen, and Nancy Ragsdale. We decided to conduct a biologic and economical benefits assessment of phenoxy herbicide use in the United States with Burnside as the Task Force chair. A Task Force of eminent weed scientists and an economist would be selected by Burnside to prepare a benefits assessment of all uses of the phenoxy herbicides. The first meeting of the Task Force on January 13, 1993 was attended by Rodney Bovey, Orvin Burnside, Herman Delvo, Clyde Elmore, Leonard Gianessi, Larry Hammond, Ellery Knake, Dennis Kopp, Carole Lembi, John Nalewaja, Michael Newton, and James Parochetti. We then selected an established weed scientist from each state, who we contacted by telephone before sending them generic questionnaires (Appendix 1) for each registered phenoxy herbicide use in their state. Our subsequent meetings were generally held in conjunction with the Weed Science Society of America annual meetings to reduce travel expenses, because most Task Force members normally attended those meetings. At the February 9, 1993 meeting, Philip Szmedra became a part of the Task Force to replace Herman Delvo as our economist. Additional meetings were held February 7, 1994, May 3, 1995, and February 7, 1996 to update Task Force members, agree on solutions to concerns needing attention, and answer questions that did arise.

Questionnaires (Appendix 1) were sent out during early 1993 to our selected weed scientist in each state plus Puerto Rico, and they were requested to respond for each registered phenoxy herbicide use in each cropland or noncropland situation. If the weed scientist did not feel qualified to provide information about some phenoxy herbicide use in their state, they were instructed to contact an individual, or individuals, with the best knowledge of the needed inforand they were requested to respond for each registered phenoxy herbicide use in each cropland or noncropland situation. If the weed scientist did not feel qualified to provide information about some phenoxy herbicide use in their state, they were instructed to contact an individual, or individuals, with the best knowledge of the needed information. Separate questionnaires were furnished for each EPA registered use of

Questionnaires were returned to Herman Delvo and he worked with Leonard Gianessi in recording and summarizing the data which Philip Szmedra then analyzed. Missing data from states caused us to alert the appropriate expert on our Task Force who in turn contacted the state weed scientists in question. If no data were received on some specific use in any state, our Task Force expert then provided such data based on results from surrounding states or from personal knowledge of the situation. Thus, we either received data from all states or we extrapolated to 100% of a specific cropland or noncropland use in the United States.

We compared estimated use of phenoxy herbicides in the various cropland or noncropland areas with the actual sale of phenoxy herbicides for the 1992 use year. If there was a discrepancy between the two amounts, the Task Force member responsible for that cropland or noncropland use made appropriate contacts and revisions to make these two estimates agree within reasonable limits. Efforts were made throughout the data analysis process to avoid double counting phenoxy herbicides uses or to avoid omissions of use areas. Actual data analysis procedures are discussed in Chapter 4.

The return rate for these phenoxy herbicides questionnaires (over 90%) was among the highest received by NAPIAP assessments. We believe such high returns were due to picking reliable respondents, contacting them for their concurrence before the questionnaires were sent, and following up by letters and telephone calls. Also, respondents were interested in retaining the use of the phenoxy herbicides in the United States.

ADDITIONAL INFORMATION ABOUT THIS REPORT

Each chapter in this report is intended to "stand alone," having its own Abstract, Literature Cited, and so forth. The various chapters are written by a recognized expert in that area of phenoxy herbicide use, economics, epidemiology, or toxicology.

For phenoxy herbicides and other herbicides that are derived from an acid, use rates are conventionally expressed in terms of weight of acid equivalent (a.e.) per unit area. For all other herbicides, use rates are conventionally expressed in terms of weight of active ingredient (a.i.) per unit area. This is how herbicide use rates are expressed in this report, but to reduce repetition we have dropped the use of a.e and a.i., and we just express rate in pounds of herbicide broadcast over one acre, which we abbreviate lb/A. Other abbreviations or acronyms used in this report are given in Appendix 2.

We have used common names for plants and herbicides, to avoid cluttering the text with the Latin names of plants and the chemical names of herbicides included in this report. However, we have provided this information in Appendices 3, 4, and 5 for those who want more detailed information.

Crops mentioned in this report are listed by common name in Appendix 3. The term crops is used in a broad sense, and it includes, for example, such things as trees in forests and orchards, and grasses in turf and rangeland.

Weeds mentioned in this report are listed by common name in Appendix 4. The term weeds is also used in a broad sense, and it includes, for example, such things as woody species and plant species that would be considered crops, if they were growing where they were wanted.

Herbicides mentioned in this report are listed by common name in Appendix 5. There, in addition to the chemical names, we have included some proprietary names (i.e., registered trade names, registered trademark names, and brand names).

And finally, Appendix 6 is a glossary of terms used in weed science, most of which have been used in this report.

ACKNOWLEDGEMENTS

Dennis Kopp, administrative advisor to this Task Force, and Nancy Ragsdale, Director of the United States Department of Agriculture NAPIAP organization, were most helpful and encouraging during the entire assessment effort. They had the needed information, data, resources, advise, and counsel when and where it was needed. It was both an educational and enjoyable experience to work with such dedicated and capable individuals.

Task Force members provided yeoman efforts when it was needed to complete this assessment in a timely manner. We appreciated their capable efforts in this "labor-of-love" as they all donated their time and effort to assuring the continued use of these important phenoxy herbicides.

Our selected state contacts were most generous with their time and talents as they met our many deadlines for the data that they were most capable of providing. The assessment results are credible because we selected those most knowledgeable and actively engaged in the areas surveyed in each state plus Puerto Rico. We could not have done this assessment without them so they should accept our sincere thanks for a job well done. These individuals are listed in the front pages of this assessment under "Respondents to Our Questionnaires."

Herman Delvo sent out the questionnaires, Leonard Gianessi compiled the survey data, Philip

Szmedra analyzed the results, and team members added the expertise that explained and summarized the results received. Also, there were many reviews of the data and manuscripts as it went through the editorial process, which added to the creditability and value of this phenoxy herbicide assessment.

Finally, we want to thank our capable typist, Patricia Kessler, who typed the various chapters and made sure that we followed basic rules of composition and editorial format. Eric Ristau produced our computer generated pie chart figures. Providing uniformity among the various chapters and readability was an objective that we strived to achieve. Also, we want to thank the publishers at Richtman Printing Companies, 301 NP Avenue, Fargo, ND 58107 who took our material and produced the finished product.

We believe that we have produced an accurate and useful assessment of the biologic and economic benefits of the phenoxy herbicides in the Unherbicides in the United States during 1992. This publication is the collaborative effort of many individuals knowledgeable about the phenoxy herbicides, and it is dedicated to all individuals who have worked for the continued use of these efficacious and economical herbicides.

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Chapter 2

The History of 2,4-D and Its Impact on Development of the Discipline of Weed Science in the United States

ORVIN C. BURNSIDE[1]

Abstract. Research in the early 1940's on 2,4-D in the United States and MCPA in England, their release after World War II, and their rapid acceptance by farmers put selective weed control in the "public spotlight" worldwide. Phenoxy herbicides have provided economical, selective, postemergence control of broadleaf weeds in grass crops and noncropland for the past five decades. Weed science technology has had a major impact during this herbicide era in increasing crop yields and reducing labor requirements for controlling weeds. Farmers rely heavily on 2,4-D and subsequently developed herbicides as a major component of their weed management program. Because the phenoxy herbicides were so effective, weed scientists initially concentrated their research and educational efforts on chemical control of weeds. This trend continues today and has impeded research on alternate weed management technology. Herbicide development will continue to be the focus of chemical company personnel because of the profit incentive. Consequently, publicly-funded weed scientists will need to emphasize preventive, cultural, mechanical, biological, and integrated control technologies so they can provide growers and land users with more balanced systems of weed management.

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INTRODUCTION

Weeds are the number one pest problem in crop production because they reduce crop yields and increase production costs (3, 4, 9). Herbicides are the most widely used class of pesticides in the United States because they are effective and economical in controlling weeds, and because weeds are the most important pest in crop production. In addition, herbicides reduce manpower and horsepower requirements and erosion-producing tillage in crop production. No exact figure has been placed on the economical benefits provided to world agriculture by the introduction of the phenoxy herbicides, which started the herbicide revolution in developed countries, but the estimated value to humankind from reduced labor requirements alone is in the billions of dollars annually.

Sale of phenoxy herbicides in the United States was about $171 million in 1992, but the loss of these herbicides would increase alternative herbicide and non-chemical weed control costs by $947 million annually (10, 16). The phenoxy herbicides still represent over 10% of herbicide poundage used in the United States, and they are the most widely used family of herbicides worldwide. Our NAPIAP report will provide EPA personnel information about the phenoxy herbicides that will be useful in their deciding whether this class of herbicides should be re-registered for agricultural crops, forestry, pastureland, rangeland, roadsides, turfgrass, aquatics, and other noncropland uses in the United States (10).

The objectives of this chapter are: (a) to trace the discovery and development of 2,4-D, and (b) to discuss the impact of 2,4-D and subsequent herbicides on the development of the discipline of weed science.

DISCOVERY AND DEVELOPMENT OF 2,4-D

The phenoxy herbicides, and 2,4-D in particular, ushered in the chemical weed control revolution in the mid 1940's. Even 51 years after its introduction, 2,4-D continues to be the most commonly and widely used herbicide worldwide. This discussion encompasses the numerous research and development pieces that completed the 2,4-D "puzzle" and its subsequent extensive utilization as a selective herbicide (Table 1). No one can give credit to all the personnel involved in the basic, applied, developmental, and marketing activities that brought 2,4-D use to fruition; however, that should not prevent an attempt at recognizing some major developmental and utilizational milestones. Table 1 is a chronological listing of some major advances in the history of 2,4-D development in the United States and worldwide, and when and where these developments occurred. Table 1.

Initial research on selective herbicides. The original research on selective herbicides was carried out by Bolley in the United States, Bonnett in France, and Schultz in Germany around 1900 (20). These researchers independently found that solutions of copper salts and other inorganic compounds would selectively control broadleaf weeds in cereals. Bolley, a plant pathologist, wrote in 1908 (6) that "When the farming public has accepted this method (selective weed control) of attacking weeds . . . the gain to the country at large will be much larger in monetary consideration than that which has been afforded by any other single piece of investigation applied to field work in agriculture." Bolley continued with, "If, therefore, this method of attacking weeds by means of chemical spray is one-quarter or one-half as successful in general operation as the writer is willing to vouch for, the money returns to the spring wheat growing states must far exceed the hopes of the most optimistic." This prophecy by Bolley regarding new methods of weed management actually came to fruition with the advent of the phenoxy herbicides in the mid-1940 era (32).

Basic research that led to 2,4-D. Botanists have long been intrigued with plant shoot and root growth and the mechanisms causing plants to respond to stimuli. Darwin from England in 1880 (33) reported that plants bend towards the light and that some influence from the tip of oat coleoptiles caused this bending or phototropic response. Boysen-Jensen from Denmark in 1911 (33) reported that when an oat coleoptile that was exposed to directional light was excised and reattached to unexposed oat tips, the bending still occurred. He concluded that the influence from coleoptile tips was thus chemical not physical. Went from the Netherlands in 1926 (33) collected the chemical from oat coleoptile tips and found it to be an active plant growth regulator. He developed a quantitative measurement of the regulator and thus stimulated considerable research in this area. Kögl and Haagen-Smit from the Netherlands in 1934 (33) reported the isolation of indoleacetic acid (IAA) from plants and human urine and identified it as the principal naturally occurring hormone (later called an auxin) in plants. When humans eat fresh vegetables they injest the hormone IAA (chemically very similar to the more stable 2,4-D) and excrete it in their urine.

Because IAA was unstable outside of plants, researchers began synthesizing and investigating the effect of IAA derivatives and homologs on plant growth activity. Zimmerman and Wilcoxson from the United States in 1935 (37) reported the discovery of phenylacetic acid and naphthylacetic acid, which affected plants by preventing premature fruit drop, inducing rooting, accelerating fruit ripening, and causing seedless tomatoes. Pokorny from the United States in 1940 (29) synthesized 2,4-D and 2,4,5-T while looking in vain for a fungicide. In June 1941, Pokorny described the chemical synthesis of 2,4-D (29). In 1942 Zimmerman and Hitchcock (36) reported that 2,4-D was 300 times more potent than indolebutyric acid, the major plant growth regulator at that time, for inducing seedless tomatoes.

Monochloroacetic acid and 2,4-dichlorophenol were used to make 2,4-D (29). Subsequently, salts were made by adding the appropriate amine or inorganic hydroxide to the acid (1). Esters were synthesized by reacting 2,4-D with the appropriate alcohols. The discovery of 2,4-D could be considered more fortuitous than systematic, but one must recognize that discovery begets further discovery, and the process seems to gain momentum and often culminates in numerous and diverse scientific advances. Went stated that, "When I worked 25 years ago with the growth hormone (2,4-D), I had many wild ideas about what it might do once it was available in large quantities, but I never dreamed that it would lead to the development of weed killers. This is an excellent example, how fundamental research may lead to the solution of very practical problems." (2). Therefore, basic research on plant growth regulators during the 1930's and earlier (33) facilitated the development of selective phenoxy herbicides in the 1940's. Thus, the discipline of weed science evolved from the field of economic botany or more specifically the study of plant growth regulators.

Military interest in 2,4-D. Interest in 2,4-D within the scientific community seemed to lose momentum during World War II when both United States and England scientists initiated secret biological warfare research on plant growth regulators with the objective of destroying enemy crops. Kraus at the University of Chicago had observed since 1936 that certain growth regulators were phytotoxic (28). Kraus was aware of the inadequacy of existing herbicides, and in 1941 he was first to propose that growth regulators might work as herbicides, because they oftenwhen both United States and England scientists initiated secret biological warfare research on plant growth regulators with the objective of destroying enemy crops. Kraus at the University of Chicago had observed since 1936 that certain growth regulators were phytotoxic (28). Kraus was aware of the inadequacy of existing herbicides, and in 1941 he was first to propose that growth regulators might work as herbicides, because they often killed test plants. In late 1941, Kraus and other prominent scientists convinced Secretary of War, H. L. Stimson, of the potential dangers

In November 1942, the United States Army began developing Camp Detrick (later renamed Fort Detrick) in Frederick, Maryland, as the center for research and testing of chemicals for biological warfare with special emphasis on crop destroying chemicals. In March 1943, the United States Army paid the University of Chicago $3500 for herbicide research completed by Kraus (28). In January 1944, research at Camp Detrick was accelerated on crop destroying herbicides. W. B. Ennis, Jr. was one of a small group of military scientists assigned to Camp Detrick, and he provided the following information regarding research by the military with the phenoxy herbicides[2].

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[2]Ennis, W. B., Jr. 1995. Personal communication from one of the military scientistsassigned to Camp Detrick, Maryland, to O. C. Burnside, Dep. Agron. and Plant Genet., Univ. Minnesota, St. Paul, MN.

While laboratory facilities were under construction at Camp Detrick, E. J. Kraus at the University of Chicago and J. W. Mitchell with the USDA at Beltsville, Maryland, were supported by contract to continue studies of the herbicidal effects of plant growth regulators. Somewhat later, a synthesis program was commenced under contract with A. S. Newman at Ohio State University.

In 1944, the biological warfare effort at Camp Detrick was stepped up by the Special Projects Division of the Chemical Warfare Service, U.S. Army under a heavy cloak of secrecy. Herbicide research with crop destruction as the objective was vigorously pursued under the direction of A.G. Norman by a team of about a dozen scientists drawn from other assignments in the services. Most were recent Ph.D. graduate students or graduates in agronomy or botany.

The research program was broadly conceived to throw light on the nature of plant responses, plant and herbicide specificities, environmental effects, effective rates of application, spray volumes and droplet size, co-agents and carriers, etc. Although attention was soon centered on halogen-substituted aryloxy acids, particularly the phenoxyacetics, many new compounds and derivatives were synthesized and screened for growth regulating properties. Sufficient amounts of the more active compounds, such as 2,4-D, 2,4,5-T and others, were procured for field trials, which included aerial application. Attention was also given to forest defoliants for the purpose of reducing cover of enemy defense positions in the expected assault on Japan.

All the research conducted at Camp Detrick was kept under military secrecy until the end of World War II. Then the scientists were free to publish results of their research. The entire June 1946 (Vol. 107) issue of the Botanical Gazette consisted of papers from Camp Detrick scientists. These papers reported well-designed experimental observations likely to be of general interest. Muchadditional information was obtained, but not all in the rigorous experimentaldetail justifying journal publication. Additional papers appeared later in the Agronomy Journal, American Journal of Botany, Science, Weeds, and other journals. The research at Camp Detrick formed a major part of the beginning of modern weed science and represented a significant part ofthe foundation knowledge on weed control with herbicides.

Among the accomplishments of the Camp Detrick scientists were the development of methods for evaluating over 1000 chemical compounds fortheir herbicidal properties, determining histological effects of 2,4-D and 2,4,5-T, cytological effects of propham, demonstration that weeds can becontrolled with ultra low-volume sprays, investigating theimportance of carriers for 2,4-D (solvents, surfactants, granules,etc.), defining the selective action of sprays on broadleaf plants,identifying the herbicidal effects of soil and water applications, anddetermining the dosages required.

The herbicide 2,4-D was patented by American Chemical Paint Co. with licensing provisions for production by Dow Chemical Co. and other companies. Commercialization followed in the mid to late 1940's.

After the war most of the scientists in the program returned to civilian life, some to universities to complete graduate programs and later to embark on careers that stemmed from their involvement in the Camp Detrick program. The Camp Detrick program, however, was not terminated. After a few months of reduced activity it was converted to a civilian staffed operation administered by the Civil Service. Security was reduced, yet certain aspects remained classified. A new staff was slowly assembled, including some of the wartime group. The program was less specifically targeted than previously and broadened to encompass various types of growth responses in plants. Synthesis and screeningwere continued and improved procedures for assessingherbicidal activity were devised. Camp Detrick research wassupplemented by contracts with universities, and research was initiated on abscission and the gibberellins. Leaf abscission and the testing of defoliants for woody species were pursued during 1961-72 under the direction of C. E. Minarik, which led to their military use that became so controversial in Vietnam operations.

All biocidal research activities were terminated in 1972, following adeclaration by President R. M. Nixon that the United States would nolonger conduct biological warfare research or develop biologicalweapons. The herbicide/defoliant research at Camp Detrick was then closed and its personnel dispersed. Some of the plant researchlaboratories and facilities were taken over by USDA-ARS scientists and personnel for research relevant to their ongoing programs."

The development of organic herbicides was greatly facilitated during World War II because of their military potential as biological warfare weapons (28). Throughout the war, United States Army research on the phenoxy herbicides was done in secrecy until January 3, 1946 when Secretary of War, R. P. Patterson, announced that more than 1000 different chemical agents had been tested on living plants. In May 1946, G. W. Merck (28), Director of the Civilian War Research Service, declared that, "...only the rapid ending of the war prevented field trials in an active theater that would, without injury to human or animal life, affect the growing crops and make them useless." Thus, herbicides were not used in chemical warfare until November 21, 1962 when the United States and South Vietnam military personnel sprayed 2,4,5-T plus 2,4-D (Agent Orange) in Vietnam to defoliate trees along military routes to reduce sniper activity (7, 11). Several Vietnam veterans in my subsequent weed science classes praised the use of Agent Orange because of the safety it provided from sniper fire for our military personnel. Antiwar protestors seized on the military's use of Agent Orange in their successful campaign to discredit this unpopular war. In the 1970's, following cessation of military hostilities, spokespersons for Vietnam veterans alleged that health problems and deaths of veterans were related to Agent Orange exposure in the military, and these allegations persisted. Thus, the public announcement on March 15, 1979 by EPA Administrator, W. D. Ruckelshaus, of an Emergency Suspension Order and Threat to Cancel further use of 2,4,5-T and silvex in the United States was strongly propelled by political pressure and not based upon scientifically developed risk assessment data. Unfortunately, on January 2, 1985 agriculturalists and foresters lost all registered uses of 2,4,5-T and silvex, effective and widely used woody plbiological warfare weapons (28). Throughout the war, United States Army research on the phenoxy herbicides was done in secrecy until January 3, 1946 when Secretary of War, R. P. Patterson, announced that more than 1000 different chemical agents had been tested on living plants. In May 1946, G. W. Merck (28), Director of

Commercial development of 2,4-D. Public plant scientists in the United States (22, 36) and England (5, 30) continued to do limited research with 2,4-D during World War II. Research in England stressed the development of MCPA, a herbicide similar to 2,4-D. MCPA was favored in England because of a plentiful supply of cresol extracted from coal and used to make MCPA versus a plentiful supply of phenol from oil refineries in the United States which was used to make 2,4-D.

In 1942, Zimmerman and Hitchcock (36) reported that the phenoxyacetic acids could induce seedless tomatoes and that they were potent synthetic plant hormones. Kraus and Mitchell tested 2,4-D at the University of Chicago and Beltsville, Maryland, but, because of the war, did not publish their results until 1944 (28). In June 1944, Mitchell and Hamner with the United States Department of Agriculture (USDA), Bureau of Plant Industry at Beltsville, Maryland, made the first public announcement of using 2,4-D as a herbicide that exhibited differential weed kill (22). Hamner then left the USDA and joined the Agricultural Experiment Station at Geneva, New York. In August 1944, Hamner and Tukey (17) caused considerable public interest when they reported that within 10 days after spraying field bindweed with 2,4-D, the weeds died. English researchers had worked with MCPA, 2,4-D, and other plant growth regulators during the early 1940's but delayed publishing their results until after World War II (5, 30).

Marth and Mitchell in 1944 (22) sprayed 2,4-D on a lawn infested with dandelions at Beltsville, Maryland, and achieved selective broadleaf weed control with no injury to the lawn grasses. Mitchell et al. (24) then conducted additional studies on a golf course in August and September 1944 and in October 1944 reported selective broadleaf weed control in turfgrass. Davis in 1945 (12), with the United States Golf Association, was the first person to direct a developmental program that would result in practical selective weed control with 2,4-D in turfgrass and lawns. Davis even sprayed 2,4-D on turfgrass of the National Capital Park Service including the White House lawn.

In 1945, workers at various state agricultural experiment stations began the first extensive field testing of 2,4-D (28). Also, the popular abbreviation, 2,4-D, first appeared in the literature in 1945. When the second annual North Central Weed Control Conference (NCWCC) workers met November 26 to 28, 1945 in St. Paul, Minnesota, Timmons indicated that data were reported from 30 cooperators with 140 experiments conducted in the United States and 36 experiments conducted in Canada (31). Kephart with the USDA chaired a panel discussion on new chemicals for weed control, and plant injury problems due to phenoxy herbicide drift were first reported (19).

Experiments in the late 1940's proved that Kraus had been right in 1941 when he first envisaged the use of plant growth regulators as herbicides (28). Military secrecy that covered the Camp Detrick research did not extend to all herbicide applications that scientists discovered. Thus, the original patent of 2,4-D and related compounds (U.S. Patent Number 2,322,761) was as plant growth regulators by John F. Lontz and assigned to E.I. du Pont de Nemours and Company dated June 29, 1943 (28). Franklin D. Jones with the American Chemical Paint Company (ACPC) filed on March 20, 1944 and received use patent 2,390,941 in December 1945 for 2,4-D as a herbicide[3]. In 1944, Mitchell paid $12.50 to ACPC and Davis paid $78.00 to Sherwin-Williams Company for a pound of 2,4-D, but the price dropped to less than $3.00 per pound in 1945 and $0.50 per pound in 1950 (12, 28). In June 1945, ACPC marketed 2,4-D under the brand name Weedone, which was the first selective, systemic herbicide produced and sold on a commercial scale. In 1945, Weedone sold so poorly that many dealers wanted to return their unsold stocks, but appropriate advertising in Better Homes (now Better Homes and Gardens) and the Reader's Digest stimulated enough sales for ACPC so that in 1946 150,000 acres were treated.[3] However, one must not overlook the tremendous impact of research by public weed scientists across the United States and Canada during 1945 and thereafter, which generated immediate farmer interest in selective weed control (12, 19, 31).

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[3]Jones, F. D. 1964. Personal communication, from the individual who patented 2,4-D as a herbicide, to C. J. Willard, Dep. Agron., Ohio State Univ., Columbus, OH who was then editor of the journal Weeds.)

The Hamner and Tukey article about field bindweed control (17) precipitated such interest among regulatory personnel, farmers, and home owners in 2,4-D that manufacturers rushed to market the herbicide. Witman wrote [4] that the agricultural chemical industry in the UnitedStates had geared upchemical industry in the UnitedStates had geared up to merchandise 2,4-D when, " . . . the industry was thunderstruck on December 11, 1945 when U.S. Patent 2,390,941, on herbicides containing chlorophenoxyacetic acids, was issued to Franklin D. Jones and assigned to American Chemical Paint Company. However, cool-headed businessmen were able to negotiate licensing of the Jones Patent for a very small royalty fee for anyone who sought to make and sell chlorophenoxyacetic acid herbicides, and the 1946 season went forward to a spectacular success for

Sherwin-Williams Company lawyers filed a lawsuit against ACPC's patent of 2,4-D as aherbicide and the following judgement was rendered:[5] "Under this settlement, the Government and the Public are given a free license to make and use, but not to sell,compositions covered by the patents involved in the litigation. In addition, the same free license is given to theGovernment and the Public under the three other Jones' patents. Americansell,compositions covered by the patents involved in the litigation. In addition, the same free license is given to theGovernment and the Public under the three other Jones' patents. American Chemical PaintCompany, Ambler, Pa., will, upon request grant licenses to any responsible party desiring tomanufacture and sell the patented compositions. The royalty to be charged has been fixed at amaximum of 2% of the net sale and price of patented compositions, with a minimum amountroyalty of $250 and a maximum total royalty for the lives of the patents of $10,000." Obviously,

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[4] Witman, E. D. 1978. Personal communication from a product development specialistwith PPG Industries, Inc. to J. H. Dawson, Res. Center, Washington Agric. Stn., Prosser,WA who was then editor of the WSSA Newsletter.

[5] Press release. 1947. Announcement of the settlement on October 24, 1947 of Sherwin-Williams' litigation against the American Chemical Paint Company patent of 2,4-D as aherbicide.

USDA officials also recognized the importance of 2,4-D and ordered human toxicity studies in 1945 and all of these proved negative. Mitchell et al. (25) reported that treating pastures with twice the normal use rates of 2,4-D produced no toxic effects in sheep and cows grazing on them, and feeding a cow 5 1/2 grams of pure 2,4-D per day for 3 months produced no ill effects to the cow or her calf fed entirely on milk from that cow. Kraus even announced that he had personally eaten one-half gram of 2,4-D per day for 3 weeks with absolutely no ill effects (19).

Several 2,4-D esters with low volatility were patented (U.S. Patent Numbers 2,523,227 and 2,523,228) in 1950 by W.H. Mullison and assigned to Dow Chemical Company. The butoxyethyl ester of 2,4-D with low volatility was patented (U.S. Patent Number 2,543,397) in 1951 by W. W. Allen and assigned to Union Carbide.

The first year of widespread testing and sale of 2,4-D in the United States was 1945 and 917,000 pounds were produced (28). Production rose to 5,466,000 pounds in 1946 and 14, 36, and 54 million pounds in 1950, 1960, and 1964, respectively. At present, the annual production of 2,4-D for use in the United States is about 47 million pounds (10, 16), so 2,4-D is still one of the more widely used herbicides in the United States and also worldwide. This continued demand for 2,4-D shows that it has markedly advanced humankind's utopian dream of lifting the hoe from the farmer's hand and reducing much of the drudgery associated with crop production.

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DEVELOPMENT OF THE WEED SCIENCE DISCIPLINE

Weed science is one of the younger academic disciplines in agriculture, first receiving significant recognition in the United States in the mid-1940's because of the introduction of the phenoxy herbicides (9, 20). Research in the early 1940's on 2,4-D in the United States and MCPA in England, their release after World War II, and their rapid acceptance stimulated selective weed control research and education worldwide. Extensive research on mechanical and cultural weed management before 1945 should have brought recognition to the discipline of weed science, but these efforts were generally identified as part of agronomic practices or crop production systems. Leighty (21), for example, wrote in the 1938 Yearbook of Agriculture that, "Weeds, aside from the noxious species, are not a serious problem on a well-organized diversified farm. Indeed, there is little excuse for such a farm to be weedy." And he goes on to say, "In some kinds of one-crop farming, weeds, while plentiful, do not prevent the production of good yields." Furthermore, even though the major benefit of tillage is weed control, many farmers tended to identify cultivation benefits as coming from tillage per se. Thus, many early agricultural scientists did not give adequate recognition to weeds and the importance of their control until the advent of the phenoxy herbicides (9, 18).

Weed control results from 2,4-D and subsequent herbicides were so spectacular that weed workers concentrated their efforts on chemical control of weeds and this shift impeded research and education on alternative weed management technology (9, 34, 35). Also, this shift in weed research, development, education, and marketing efforts over the past five decades has impacted all areas of weed science.

The objectives of this section are: (a) to enumerate the economic importance of weeds and the extent of herbicide use, and (b) to discuss the impact of 2,4-D on the development of the herbicide industry, regulatory agencies, farmers, and publicly-funded weed scientists.

Monetary losses from weeds. In the early 1960's, USDA scientists estimated the relative proportion of total losses in productivity of United States agriculture from insect pests to be 10%, soil erosion 13%, livestock diseases 17%, plant pathogens 26%, and weeds 34% (3). In addition, farmer costs were about three times higher for controlling weeds than for controlling plant pathogens and insect pests combined. In 1971, after substantial use of pesticides for controlling pests (various biological organisms that reduce crop yields or quality) in agriculture, USDA scientists estimated annual United States losses to crop pests as follows: nematodes 3%, plant pathogens 27%, insect pests 28%, and weeds 42% of total pest losses in crop production (4). These relative loss comparisons probably have not changed greatly in the past two decades. Annual weed losses (mainly reduced crop yields and increased costs of control) in the United States were estimated to be over $20 billion in 1993[6]. Thus, weeds remain an important impediment to crop production because they are omnipresent, they reduce crop yields, and weed control often constitutes the major cost of producing a crop even though we have eliminated much of our reliance on manual weed control. It must be recognized, however, that crop losses from weeds, costs of control, and crop production costs in general would be much greater if farmers were forced to revert to crop management methods used prior to 1945.

Herbicide costs and usage. In 1991, pesticides were a $26.8 billion industry worldwide with sales totaling $6.4 billion in the United States or 24% of worldwide pesticide sales (23). Herbicides represented about 65% of total pesticides used in the United States in 1990 and 85% of pesticides used on cropland (13). Herbicide use on crops in the United States grew from 115 million pounds in 1966 to a peak of 500 million pounds in 1982 when over 90% of the acreage of major crops was treated with one or more herbicides (15). Since 1982, total pounds of herbicides used has decreased about 10% because of the introduction of compounds that are active at lower rates, reductions in use rates of older herbicides, and government sponsored acreage diversion programs (9). The phenoxy herbicides still represent about 10% of total herbicide usage in the United States.

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[6] Bridges, D. C. 1993. Personal communication from the chairman of the Weed Science Society of America, Weed Loss Committee, to O. C. Burnside, Dep. Agron. and Plant Genet., Univ. Minnesota, St. Paul, MN.)

Impact of 2,4-D on the herbicide industry. The phenoxy herbicides stimulated chemical industry involvement in herbicide development because industry personnel recognized the weed control need in agriculture and noncropland and the profit potential of this technology. The spectacular results with 2,4-D stimulated an industry-wide search for additional herbicides, which ushered in the herbicide era that has lasted for five decades. Total numbers of hedevelopment because industry personnel recognized the weed control need in agriculture and noncropland and the profit potential of this technology. The spectacular results with 2,4-D stimulated an industry-wide search for additional herbicides, which ushered in the herbicide era that has lasted for five decades. Total numbers of herbicides available in the United States as listed by Timmons (32) or in Weed Science Society of America journals (9) were 14 in 1940, 25 in 1950, 61 in 1960, 131 in 1970, 156 in 1980, and 145 in 1990. Thus, industry rapidly expanded personnel in herbicide development, manufacture, and sales in order to exploit the market potential of herbicides that increased rapidly from 1945 until about 1982 when herbicides use peaked in the United States (15). Since 1982 there has been increased competition among chemical companies because the herbicide market in the United States had matured and profits were decreasing as companies competed for the same market share rather than exploiting mainly untapped markets. T[7] projects that this consolidation may continue until only six full-service pesticide companies (synthesis of pesticides on through to sales) will remain worldwide.

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[7]Carpenter, W. D. 1995. Personal communication from the retired Vice President andGeneral Manager, New Products Division, Monsanto Company, St. Louis, MO to O. C. Burnside, Dep. Agron. and Plant Genetics, Univ. Minnesota, St. Paul, MN.)

Impact of 2,4-D on the regulatory agencies. The phenoxy herbicides were vigorously promoted by personnel of various weed control regulatory agencies that were already in place when 2,4-D was first sold in 1945. For example, the Connecticut legislators enacted in 1726 a European barberry control law which was the initial United States program to aid in the control of black stem rust of wheat, but a more effective barberry control law was enacted in 1917 that encompassed 13 North Central and Western States (32). Federal and states' Ribes spp. Quarantine and Eradication Laws aimed at the control of white pine blister rust were initiated during 1912 to 1919 in 26 states. In 1914 Virginia passed a law requiring the eradication of red cedar as an aid in the control of apple rust, and similar legislation was also enacted in four other states. Numerous States and Canadian Provinces enacted Seed Laws beginning in 1821 in Connecticut and Noxious Weed Control Laws beginning in 1872 in Minnesota, and these regulatory personnel immediately recognized the importance of 2,4-D in carrying out their legislative mandates (32). However, 2,4-D did not turn out to be the panacea weed control herbicide that it was advertised to be, and thus no noxious weeds were eradicated (2).

Laws aimed at the prevention or spread of undesirable weeds such as Seed laws have been moderately effective in reducing the spread of weeds, Weed Control Laws more often than not have been ineffective, and Eradication Laws have been ineffective because eradication of a weedy species from a large area has proven to be an impossible objective (8). Thus, the impact of regulatory efforts in weed management and financial support of these regulatory programs has eroded over the past several decades. However, regulation of pesticides by the EPA and similar state agencies has increased over the past several decades.

Impact of 2,4-D on the farmer. The phenoxy herbicides raised weed management to a higher level, and producers accepted this new technology rapidly and with enthusiasm, because they were able to achieve better weed control with less labor and expense (20, 31, 32). Phenoxy herbicides provided effective, economical, and selective broadleaf weed control in small grains, corn, sorghum, pastureland, rangeland, and turfgrass.

I remember when farmers commonly lost crops to weeds such as quackgrass, Canada thistle, or wild mustard. Now such a farmer would be considered a poor steward of the land and would be the topic of conversation at the local coffee shop. I also remember having to get off the tractor and remove wild mustard plants, or they would clog my father's small grain binder. Then, 2,4-D was introduced, and we were all amazed at its ability to selectively control wild mustard in small grains at a very economical cost (see picture on the cover page).

Farmers began expecting selective herbicides for numerous other cropping systems, and the agricultural chemical industry responded positively because of the profit potential. Herbicides such as 2,4-D and MCPA established the concept of postemergence, selective weed control; chloramben and atrazine established preemergence, selective weed control; and EPTC and trifluralin established preplant-soil-incorporated, selective weed control. Examples of changes in herbicide technology over the past five decades are inorganic to organic herbicides, nonselective to selective herbicides, postemergence to soil-applied (some incorporated) herbicides and now back again, mechanical to more chemical control of weeds, single herbicides to mixtures and even multiple applications, formulated herbicides used alone to utilizing various herbicide additives, and crops bred or transformed for tolerance to specific herbicides rather than herbicides being screened for crop tolerance (9).

The American farmer relies heavily on herbicides as the major method of weed control, and herbicides allow them to farm more and more acres (9, 14, 35). Herbicide use and farm equipment development has resulted in substantial decreases in number of farmers and farm laborers required for crop production in the United States (26). Adequate alternative methods of weed control are not currently available in the event of future restrictions on herbicide usage that may result because of public concern about herbicides in ground and surface water, toxicity to humans, chronic health effects, food safety, and wildlife mortality (9). Operators of large acreage farms will continue to demand more and better selective herbicides; whereas, an increasing group of organic and smaller acreage farmers are looking for alternative and more economical weed management methods (34, 35).

Impact of 2,4-D on publicly supported weed scientists. The phenoxy herbicides had such an impact on weed technology that most publicly-supported weed scientists became engrossed in chemical weed control research and education endeavors (9, 34). Thus, weed control methods have changed because weed scientists slighted or abandoned alternative weed management technology. We have witnessed five decades in which most of the weed science research in the United States has had some connection with herbicides. However, this herbicide era has markedly advanced our ability to manage weeds in cropland and noncropland, and greatly reduced labor requirements and crop losses in agricultural production.

University and USDA-Agricultural Research Service (ARS) administrators began hiring weed scientists after the advent of 2,4-D, but employment numbers never reflected the fact that weeds were a greater production hazard than either plant diseases or insect pests (2, 9, 27). Possibly administrators rationalized that the herbicide industry would support or supply many of the weed science research and educational needs. For example, federal funding for pest management research at universities in fiscal year 1991 was $61 million for Entomology, $50 million for Plant Pathology, $9 million for Nematology, and $6 million for Weed Science (27). In 1995, Ogg (27) contacted the business managers of the Entomological Society of America to learn that they had 8100 members and 6075 were publicly-funded, the American Phytopathological Society had 5000 members and 4250 were publicly-funded, and the Weed Science Society of America had 2200 members and 550 were publicly-funded. Such public-funding and hiring practices forced the few publicly-funded weed scientists to conduct research and education activities in the areas where they could make the most rapid progress and receive industry support, i.e., herbicide technology.

Is it any wonder that recent assessments of weed management technology (9, 14, 34, 35) have shown that farmers place an overwhelming emphasis on chemical weed control technology? If public weed scientists do not conduct preventive, mechanical, cultural, biological, and integrated weed management research, it will not be done. We coverwhelming emphasis on chemical weed control technology? If public weed scientists do not conduct preventive, mechanical, cultural, biological, and integrated weed management research, it will not be done. We cannot expect to entice large numbers of chemical company weed scientists into researching alternative weed control technology. They must research, develop, and sell marketable products that return a profit or there will be no herbicide industry (9). Most alternative weed management methods do not have the profit potential to merit private-sect

FUTURE TRENDS IN WEED SCIENCE

One can predict that weed science will continue to show modest growth in public research, education, and herbicide regulation areas, as well as in the area of private consulting; however, the number of weed scientists within the chemical industry will decrease because of continuing consolidation of pesticide companies (9). Academic employment opportunities should increase for those trained in the areas of weed biology, ecology, and management. Weed control activities will move from the largely chemical approach to systems involving greater use of preventive, cultural, mechanical, biological, and integrated weed management activities. Herbicides will continue to be important in weed management, but they will be used more selectively and judiciously. The use of postemergence herbicides may increase as they will be used to "back up" alternative weed control methods so that farmers do not experience crop yield loss while initiating the use of new weed management technology. However, public weed scientists must redirect their activities after five decades of largely herbicide-focused research and undertake a major change in weed research objectives to develop basic information about weeds and problem solving research using integrated weed management systems (9, 34, 35).

If there is one thing that I have learned from 35 years of weed research, it is that there is no panacea weed control method. Thus, one must emphasize an integrated approach to weed management, as certain weed species have survived all individual weed control methods that humankind has so far devised. Greater use of on-farm research may aid in developing the needed weed management technology. Public weed scientists have exciting years ahead as they emphasize research and education directed toward weed biology and life histories, weed seedbanks, seed and bud dormancy, cover and smother crops, rotation of crops with different life cycles, weed-competitive crops, biological and ecological weed management, postemergence herbicide technology, precision herbicide applications that vary rates or herbicides based on soil type and climate and weed species, environmentally benign herbicides or mycoherbicides, spray equipment activated by the presence of weeds, interference modeling of crop-weed systems, reduced-tillage crop production systems, and the destruction or inactivation of weed propagules to develop integrated, sustainable, and environmentally safe weed management methods.

We should not abandon herbicides, but we can use them more judiciously (9). We need to conserve natural resources such as soil and fossil fuels while increasing the productivity, profitability, and competitiveness of agriculture in the United States. Also, a major challenge for us in the future is to optimize weed management systems to meet or exceed the water quality and environmental impact standards demanded by the public. Implementing alternative weed control methods, not more monitoring programs, is the way to solve problems of pesticide contamination of water or the environment. To accomplish these objectives, an increase in public funding for the development of weed science as a discipline must occur because development of alternative weed management methods will not attract substantial private funding.

Now weed scientists must settle down and attend to research and educational endeavors that have been put on the "back burner," while continuing to pursue the judicious use of herbicides. The future will be just as exciting as the past, as weeds do not give up their turf easily.

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Table 1. Chronology of selected developments in the history of phenoxy herbicides (generally 2,4-D) mainly in the United States but also worldwide.a

Year	Individuals or groups	Development
1880	Darwin	Studied tropisms in plants (33).
1908	Bolley, Bonnet, and Schultz	Selectively controlled broadleaf weeds in small grains with copper salts (20).
1911	Boysen-Jensen	Documented chemical control of tropisms in plants (33).
1926	Went	Measured quantitatively a natural plant growth regulator (33).
1934	Kögl and Haagen-Smit	Identified IAA as the natural plant growth regulator (33).
1935	Zimmerman and Wilcoxson	Discovered PAA and NAA to be plant growth regulators (36).
1940	Pokorny	Synthesized 2,4-D and 2,4,5-T (29).
1941	Kraus	Proposed that growth regulators might work as herbicides (28).
1942	Zimmerman and Hitchcock	Found 2,4-D to be the most active of the plant growth regulators (36).
1942	Stimson	Initiated biological warfare research in the U.S. with crop killing herbicides (28).
1942	U.S. Army	Established Camp Detrick for biological warfare research (28).
1943	Lontz, DuPont Co.	Patented 2,4-D as a plant growth regulator (28).
1944	Mitchell and Hamner	Made the first public announcement that 2,4-D was a selective herbicide (22, 28).
1944	Marth and Mitchell	Selectively controlled dandelions in turfgrass with 2,4-D (22).
1944	Hamner and Tukey	Selectively controlled field bindweed with 2,4-D (17).
1945	NCWCC scientists	Used the name "2,4-D" in the literature for the first time (28).
1945	ACP Co.	Were the first to market 2,4-D as a selective herbicide (28).
1945	Davis	Used 2,4-D first for commercial control of weeds in turfgrass (12).
1945	NCWCC scientists	Conducted extensive research with 2,4-D as a selective herbicide (19, 31).
1945	Mitchell, Hodgson, and Gaetzens	Reported that animal toxicity studies with 2,4-D were negative (25).

1945	Kraus	Ate 1/2 gram of 2,4-D per day for 3 weeks with no ill effects (19).
1945	Kephart	Chaired a NCWCC symposium on 2,4-D in which drift damage was reported (19).
1945	Jones, ACP Co.	Patented 2,4-D as a selective herbicide (28).
1946	Patterson	Reported that the U.S. Army had screened over 1000 chemicals for their crop killing potential (28).
1946	U.S. Army scientists	Reported on their herbicide research at Camp Dietrick, filling the entire June issue of the Botanical Gazette (28).
1947	Sherwin-Williams Co.	Completed litigation against ACP's 2,4-D patent (28).
1950	Mullison, Dow Co.	Patented several low volatile 2,4-D esters (28).
1951	Allen, Union Carbide Co.	Patented butoxyethyl ester of 2,4-D (28).
1962	U.S. Army	Sprayed Agent Orange as a defoliant in Vietnam (7, 11).
1970	USDA-ERS	Estimated that restricting phenoxy herbicide use would cost U.S. farmers $290 million annually (4).
1979	Ruckelshaus, EPA	Suspended all uses of 2,4,5-T and silvex in the U.S. (7, 11).
1985	U.S. District Court, Washington, DC	Banned all use of 2,4,5-T and silvex in the U.S. (7, 11).
1988	Agriculture Canada	Reported that banning phenoxy herbicides would cost Canadian growers $420 to $488 million annually (16).
1990	EPA	Established the Health Advisory Level of 70 ppb of 2,4-D in potable water (16).
1992, 1994	EPA	Received reports from Advisory Committees of toxicologists indicating that 2,4-D was not a carcinogen (16).
1995	Industry Task Force II	Submitted the 2,4-D risk assessment re-registration data requested by EPA (16).
1996	NAPIAP	Presented a progress report of the phenoxy herbicide benefits assessment (10).

[a]Abbreviations used were 2,4-D [(2,4-dichlorophenoxy)acetic acid], IAA (indoleacetic acid), PAA (phenylacetic acid), NAA (naphthylacetic acid), 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid], NCWCC (North Central Weed Control Conference), ACP (American Chemical Paint), USDA (United States Department of Agriculture), ERS (Economic Research Service), ppb (parts per billion), EPA (Environmental Protection Agency), and NAPIAP (National Agricultural Pesticide Impact Assessment Program).

Chapter 3

Risk Assessment of Phenoxy Herbicides:

An Overview of the Epidemiology and Toxicology Data

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Abstract. Despite the societal benefits of phenoxy herbicides, results from a series of epidemiologic studies have raised questions about possible human health risks associated with their use. However, the results from these studies have been inconsistent and may have been due to errors in the reporting of pesticide exposures. Recent methodologic research indicates that pesticide exposures may be reported inaccurately to such a degree that it may not be possible to interpret the results from epidemiologic studies where these data have been provided by study participants. Therefore, the evidence from such epidemiologic studies should not be given much weight when determining whether there is a causal association between cancer and phenoxy herbicides in general, or between cancer and 2,4-D specifically. Thus, the only conclusion that can be drawn from the previously conducted epidemiologic studies is that the data are insufficient to assess the carcinogenicity of phenoxy herbicides, or 2,4-D, in humans. Recent toxicologic research indicates that 2,4-D alone is not carcinogenic and suggests no known mechanism by which it could be carcinogenic. Rarely are chemicals carcinogenic in humans, but not in animals. Furthermore, a review of noncarcinogenic effects suggests that individuals who are exposed to 0.01 mg/kg/day of 2,4-D over their lifetimes would not experience an appreciable risk of toxic effects. Based upon data from exposure studies, the general public is exposed to levels of 2,4-D that are below this reference dose; therefore, the general public should not be at risk of adverse health effects due to 2,4-D exposure. Occupational exposures, however, may exceed the reference dose. To reduce risk, workers should use appropriate protective equipment.

INTRODUCTION

The societal benefits associated with use of phenoxy herbicides have been described in other chapters. Despite these benefits, possible risks also must be considered in the re-registration of phenoxy herbicides. In this context, risk is defined as the likelihood that some adverse effect to humans will occur (69). In general, pesticides may be thought to pose a certain amount of risk because: (a) most pesticides are synthetic chemicals, which are deliberately released into the environment; (b) pesticides are specifically designed to harm or kill living things, and they have the potential to be toxic to nontarget organisms, including humans; and (c) many humans may be exposed to pesticides, either occupationally, or from nonoccupational sources (47, 69). However, the degree of risk or lack thereof varies with the specific pesticide, as well as with the frequency, intensity, and duration of exposure (69).

Initially, much of the concern about pesticides was directed at adverse ecological effects. During the last few decades, however, the focus of concern has shifted from the environment to human health

(69). The purpose of this chapter is to review the epidemiology and toxicology data relating to phenoxy herbicides, or more specifically, 2,4-D.

EPIDEMIOLOGY

Epidemiology background. Epidemiology is the study of the occurrence of, and factors related to, states of health and disease in human populations. The potential for pesticide exposures to cause cancer has been the foremost human health effect of concern; therefore, this section of the review will focus on those epidemiologic studies that have evaluated phenoxy herbicides in relation to cancer. In the past decade, a number of reviews of the epidemiologic data relating to pesticides and cancer have been published (2, 4, 5, 7, 8, 10, 11, 12, 16, 20, 35, 38, 42, 48, 49, 55, 62). Thus, the summary of the epidemiologic literature presented here is, in part, drawn from these reviews. Furthermore, this review is not intended to be comprehensive, but instead, it includes select articles that reflect on the cancer risks associated with human exposure to 2,4-D or other phenoxy herbicides. In addition, the key methodologic issues surrounding these epidemiologic studies are discussed, as well as the results of epidemiologic studies designed to investigate these issues.

Study designs and risk estimates. In the late 1970's, the first analytic epidemiologic investigations of phenoxy herbicides and cancer were begun. Prior to that time, only descriptive studies had been done and these typically provide less useful information.

The analytic epidemiologic studies conducted have examined either specific types of cancer (i.e., case-control studies) or specific exposed populations (i.e., cohort studies). In these case-control studies, people who have a specific cancer (i.e., cases) and people who do not have the cancer (i.e., controls) are identified. Then, information about prior exposure to a suspected carcinogen is obtained for both the cases and controls. The odds of exposure among the cases is compared to the odds of exposure among the controls, and this risk estimate is called the odds ratio (OR). The way to interpret the value of the OR is as follows: (a) if the OR equals 1.0, the cases and controls have been exposed equally; (b) if the OR is less than 1.0, the controls have been exposed more than the cases; and (c) if the OR is greater than 1.0, the cases have been exposed more than the controls. If exposure is more common among the cases than the controls, the exposure may be associated with the occurrence of the cancer.

In a cohort study, groups of individuals with and without exposure are followed over time. The incidence of disease in the exposed group is compared to the incidence of disease in the unexposed group and this risk estimate is called the relative risk (RR). The way to interpret the value of the RR is as follows: (a) if the RR equals 1.0, the incidence of disease is equal among the exposed and unexposed; (b) if the RR is less than 1.0, the incidence of disease is higher for the unexposed than for the exposed; and (c) if the RR is greater than 1.0, the incidence of disease is higher for the exposed than for the unexposed. If the incidence of disease is more common among exposed persons than among those who are unexposed, the exposure may be associated with the occurrence of the disease. In addition, the OR and RR usually are provided with an interval that shows the variability in the risk estimate and specifies the probability that the interval includes the true risk. This interval is called the confidence interval (CI) and it is used to help determine whether the risk estimate is meaningfully different from 1.0. The risk estimate is said to be significantly different from 1.0 if the CI does not include 1.0.

Summaries of the case-control and cohort studies are presented separately below. The case-control studies are discussed first because findings from the early case-control studies prompted much of the epidemiologic research on phenoxy herbicides, including 2,4-D.

In the summaries and tables, reference is made to the following exposures: "pesticides," "herbicides," "phenoxy herbicides," and "2,4-D." These terms are presented as such to accurately reflect how the questions were asked in the epidemiologic studies. For example, in a particular study, participants may have been asked, "Did you ever use herbicides?" and "Did you ever use 2,4-D?"

Case-control studies. The majority of case-control studies have focused on the following types of cancer: (a) soft-tissue sarcomas (STS), (b) Hodgkin's disease (HD), and (c) non-Hodgkin's lymphoma (NHL). In Sweden, a clinical observation (28) of a number of patients with STS and prior exposure to phenoxy herbicides led to the first case-control study (30). In this case-control study in northern Sweden, a fivefold increase in risk for STS (OR = 5.3; 95% CI = 2.4 to 11.5) was observed for exposure to phenoxy herbicides. However, 2,4,5-T was frequently used by those who were exposed, and this phenoxy herbicide has been found to contain 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD) as a contaminant. Another case-control study subsequently was undertaken in southern Sweden to try to confirm these findings (25). In southern Sweden, commonly used phenoxy herbicides included 2,4-D, MCPA, and others thought to be free of 2,3,7,8-TCDD. The risk for STS associated with exposure to any phenoxy herbicides found in this second Swedish study was nearly sevenfold (OR = 6.8; 95% CI = 2.6 to 17.3). A fourfold risk (OR = 4.2; CI not provided) was reported for exposure to phenoxy herbicides not contaminated by 2,3,7,8-TCDD.

Around the same time, a number of patients with malignant lymphoma and previous exposure to phenoxy herbicides was reported in Sweden (29). Once again, a case-control study was performed to see if there was a relation between this type of cancer and exposure to these herbicides (32). The results of this case-control study of malignant lymphoma showed almost a fivefold increase in risk (OR = 4.8; 95% CI = 2.9 to 8.1) with exposure to phenoxy herbicides. Separate results were not provided for HD and NHL, but were reported to be similar.

Due to the substantial risks observed in the early Swedish studies and the potential for widespread exposure to phenoxy herbicides, a number of case-control interview studies of STS, HD, and NHL followed in Sweden, New Zealand, Italy, United States, and Australia (21, 31, 33, 34, 53, 54, 56, 58, 59, 60, 61, 65, 70, 71, 74). The basic design features and results of these studies are summarized in Table 1 and are not discussed further.

Despite the strong associations observed by Swedish researchers, almost all of the other studies conducted elsewhere have failed to confirm these findings. In Kansas, Hoar et al. (34) found a significant association with NHL and use of phenoxy herbicides and 2,4-D. In addition, the risk of NHL significantly increased with the number of days of herbicide exposure per year. OR's of 1.4, 1.6, 2.6, and 6.0 were found for using herbicides for 1 to 5, 6 to 10, 11 to 20, and more than 20 days per year, respectively. Frequency of use data were not collected for specific pesticides such as 2,4-D. In Nebraska, this same researcher and colleagues (74) observed a nonsignificant elevation in risk for NHL attributable to 2,4-D. In addition, an association was suggested between increasing days of 2,4-D exposure per year and risk of NHL.

Cohort studies. Cohort studies that have examined cancer risk and phenoxy herbicides have included those persons potentially exposed during manufacturing or application. STS, HD, and NHL are relatively rare cancers and are believed to occur many years after initial exposure to a carcinogen; therefore, most of the cohort studies conducted to date have not had either a sufficiently large cohort or an adequate number of years of follow-up to be informative. The relevant cohort studies (14, 15, 24, 43, 44, 45, 52, 66, 67, 68) are summarized in Table 2 and are not described further. The findings from the cohort studies do not support those of the Swedish case-control studies.

Methodologic issues. Epidemiology is fraught with inconsistent studies; however, it is unusual for risk estimates to vary as greatly as those observed in the case-control studies of STS, HD, and NHL and phenoxy herbicides. Several papers (6, 7, 8, 9, 12, 13, 50) have been published about methodologic issues that may explain the inconsistent case-control study findings. Error in the measurement of exposure has been suggested as one of the possibleexplanations and continues to be the primary methodologic issue of concern (9).

Overview of exposure measurement concepts. Error in the measurement of exposure, also called exposure misclassification, is the difference between the measured exposure and the true exposure. Although exposure misclassification occurs to some extent in almost all epidemiologic studies, it is particularly problematic because it leads to bias in the risk estimate. This type of bias is called misclassification or information bias. Differential misclassification occurs when the exposure measurement error differs according to disease status; nondifferential misclassification is independent of disease status. Nondifferential misclassification usually results in an underestimate of the true risk. Differential misclassification can either underestimate or overestimate the risk and can make it impossible to draw any conclusions from the study results. Case-response or recall bias is a form of differential misclassification of exposure in which cases report exposures differently than controls. Compared to controls, cases may better recall or falsely report exposures in an attempt to identify what may have caused their disease (3).

Information about the validity and reliability of measured exposure data is needed to determine the extent and direction of exposure misclassification. Validity refers to the accuracy of a measure (i.e., whether it correctly measures the true exposure) and reliability refers to the reproducibility of a measure (i.e., whether it consistently provides the same results on two or more occasions). Long-term reliability refers to the reproducibility obtained when the measurements are made a long time apart and short-term reliability refers to the reproducibility obtained when the measurements are made a short time apart. Reliability is only important for what it reveals about validity. If an exposure measure is not reliable, it cannot be valid. A reliable exposure measure, however, does not imply a valid measure. Therefore, it is preferable to evaluate the validity of an exposure measure. In order to measure the validity of an exposure measure, however, the true exposure must be known. A measure of the true exposure usually is not available or is not practical to use; otherwise, this perfect measure would be used instead of the less accurate one. As a result, the "validity" of an exposure measure often refers to how the measure under study compares with a measure that is deemed to be the most accurate (i.e., a "gold standard") (3).

Percentages of agreement often are calculated to assess the reliability of an exposure measure. Sensitivity and specificity often are calculated to assess the validity of an exposure measure. Sensitivity is calculated as the percentage of truly exposed persons who report that they have been exposed. Specificity is calculated as the percentage of truly unexposed persons who report that they have not been exposed. Ideally, a valid exposure measure will have both high sensitivity and high specificity.

A number of questions have been raised regarding the exposure assessment procedures in epidemiologic studies of pesticides and cancer. STS, HD, NHL, and other cancers of interest occur infrequently and are characterized by long cancer induction periods following exposure. Consequently, studies of these cancers most often have used a case-control design to alleviate the need for large numbers of subjects and a long follow-up period. Therefore, information about past pesticide exposures usually has been obtained by interviewing subjects, or when necessary, proxy-respondents. The accuracy of these pesticide exposure measurements is dependent on the memory or recall of the individuals being interviewed.

The ability to recall details related to pesticide use may decrease with time; thus, the accuracy of data regarding early uses of pesticides may be most suspect. Unfortunately, these data may be the most relevant with regard to initiation of cancer (6). Recall is hindered by the fact that subjects exposed to pesticides almost always have used a number of different pesticides during their lifetimes, and the available and recommended pesticides have changed over the years (8). Recall also is difficult because most subjects use pesticides relatively infrequently, often only seasonally (8, 12, 13).

Proxy-respondents (e.g., spouses, siblings, children, and parents) are interviewed on behalf of subjects when the subjects themselves are unable to be interviewed due to death, illness, dementia, or some other reason. In case-control studies of pesticides and cancers, the cancers being studied often have high death rates; thus, by necessity, proxy-respondents must be used. However, the proxy-respondents may never have known which pesticides the subjects used. It is commonly believed this lack of knowledge would cause proxy-respondents' recall of pesticide use to be less than study subjects' recall (8, 9), but it also is possible that proxy-respondents may be prone to case-response bias.

In the Nebraska study, the risk of NHL associated with 2,4-D was higher among subjects with proxy-respondents than among self-respondents (74). For proxy-respondents, OR's of 2.2, 2.2, and 2.4 were found for handling 2,4-D for 1 to 5, 6 to 20, and more than 20 days per year, respectively. For self-respondents, the corresponding OR's were 1.0, 1.6, and 1.4. Similarly, in a case-control study of NHL and leukemia conducted in Iowa and Minnesota (18, 21), the proxy-respondent OR's for use of 2,4-D for 1 to 4, 5 to 9, and more than 10 days per year were 0.8, 1.0, and 2.5, respectively (51). The self-respondent OR's for the same categories of use were 0.5, 0.2, and 0.7. Thus, in the case-control studies in Nebraska and in Iowa-Minnesota, there was evidence that case-response bias may have occurred.

Methodologic studies. The issues noted above illustrate the difficulties associated with retrospectively obtaining information about pesticide exposures and the need to assess the reliability and validity of reported use of pesticides. Given the complexity of pesticide exposures and the controversy surrounding the inconsistent findings from case-control studies of pesticides and cancer, it is remarkable how little methodologic research has been conducted in this area (17, 19, 30, 34, 39, 40, 70). Such research may not have been undertaken because it has been assumed that pesticide exposure misclassification always would reduce estimates of risk (i.e., that the misclassification is nondifferential) or because of the resources required. The few studies that have been done are summarized in Table 3 and described briefly below.

In the first case-control study of STS and pesticides conducted in Sweden, 50 employers were mailed a questionnaire to verify employment and use of phenoxy herbicides or chlorophenols reported by study subjects (30). Only a small proportion (40%) of the employers responded. Due to a lack of records regarding exposures to these chemicals, responses received mainly were based on employers' recall. The authors stated that the results obtained were uncertain and difficult to interpret. Despite these limitations, the authors concluded that the reported use of phenoxy herbicides probably was reliable because a high degree of agreement was observed for use of chlorophenols in sawmills or the pulp industry. The measure used to assess agreement and the actual agreement observed were not provided. In addition, possible differences in agreement for cases and controls were not evaluated.

A similar approach was used in the case-control study of STS and NHL in Washington state (70). In this study, supervisors and coworkers were contacted by telephone to corroborate self-reported exposures to specific phenoxy herbicides, chlorophenols, or other chemicals for those jobs with potential exposures to these chemicals. The authors indicated that confirmation of subjects' responses was provided in essentially all instances in which the supervisors or coworkers were successfully reached. No response rate was given, but a greater number of supervisors and coworkers could be reached for recent occupations. In addition, the majority of verification contacts attempted (approximately 80%) were for recent occupations. The authors also stated that there were no significant differences in agreement for cases and controls. No agreement percentages were provided.

In the case-control study of malignant lymphoma and STS conducted in Kansas, pesticide suppliers were interviewed on behalf of 110 subjects with farming experience to see whether they could confirm the pesticide use reported by the farmers (34). For these interviews, the suppliers relied on their memories or written records, or both (6, 12). Overall agreement between the farmers' and suppliers' responses regarding use of pesticides was only about 50% (6). When only the previous 10 years were considered, agreement between suppliers and subjects was higher. Suppliers typically reported less pesticide use than the farmers (34). For all subjects, the percentage of agreement for herbicides was approximately 60%. Similar percentages were found for cases and controls (12, 13, 34). Agreement was considerably lower for specific years of exposure to herbicides (12, 13). For use of 2,4-D, agreement was 83% for NHL cases and 74% for controls (6). The number of cases and controls who reported using herbicides was multiplied by the percentage of verified herbicide use and the OR for NHL was recalculated. The recalculated OR was 1.8, which was higher than the OR of 1.6 calculated from only the interview responses (34). A recalculation of the OR was not performed for 2,4-D. The authors attributed the lack of agreement between the two sources to the large number of suppliers farmers could have used, the closing of suppliers, the lack of historical records about pesticide purchases at many suppliers, the long period of time during which farmers had purchased pesticides, and the number of pesticides purchased (6).

In Iowa, 95 Iowa male controls from the Iowa-Minnesota case-control study of NHL and leukemia (18, 21) were reinterviewed about selected agricultural pesticides that the farmer previously had reported using, and these responses were compared with responses provided by proxy-respondents (19). The percentages of agreement for 2,4-D use before and after 1960 were 97 and 95%, respectively. In each time period, proxy-respondents reported slightly more subjects as exposed to 2,4-D than the subjects reported themselves. Agreement for the usual number of days herbicides were used per year was 52%. Similarly, the agreement percentages relating to the average annual frequency of 2,4-D use before 1960 was 48%, while after 1960 it was 56%. Because the study included only controls, no assessment could be made of possible reporting differences for cases and controls. The authors concluded that agreement between the responses of subjects and proxies was excellent and that data from proxy-respondents will be sufficient for epidemiologic purposes, assuming that differential recall is minimal.

In another study, 270 male cancer cases were initially interviewed for a multicenter case-control study of STS, HD, NHL, and other cancers (17). For the cases who died during the 4-year study interval, proxy-respondents also were interviewed. Accuracy of data from proxy-respondents was assessed by calculating theother cancers (17). For the cases who died during the 4-year study interval, proxy-respondents also were interviewed. Accuracy of data from proxy-respondents was assessed by calculating the sensitivity and specificity (i.e., data from the self-respondents were assumed to be the "gold standard"). Agreement between self- and proxy-respondents for pesticide and herbicide exposure data was low (sensitivities ranged from 14 to 51% and specificities ranged from 95 to 100%). The sensitivity for herbicides used infarming was approximately 45%, and the specificity was approximately 95%. For herbicideproducts containing 2,4-D, the sensitivity was 35% and the specificity was 100%. Becausethe study included only cases, no assessment could be made of possible reporting differen

As part of a large methodologic study done by one of us (39), proxy-respondents wereinterviewed for 328 Minnesota subjects from the Iowa-Minnesota case-control study of NHLand leukemia (18, 21) who died or became incompetent since the initial interview (40). Asquestions increased in detail, agreement percentages decreased. Agreement percentagesranged from 48 to 91% for specific pesticides, with the majority between 60 and 80%. Among the NHL cases, leukemia cases, and controls, the agreement percentages for allherbicides were 79, 70, and 71%, respectively. For these same groups of subjects, theagreement percentages for 2,4-D were 75, 61, and 64%, respectively. Exposuremisclassifications had varying effects on the OR's and 95% CI's. Generally, OR's calculatedfrom proxy respondent data were less than those from self-respondent data; however, severalexceptions occurred. For example, proxy-respondents had an OR for leukemia of 2.4 (95%CI = 0.9 to 6.0) for herbicides; whereas, the corresponding OR for self-respondents was 1.1(95% CI = 0.5 to 2.3). The leukemia OR for 2,4-D was 2.6 (95% CI = 1.1 to 6.3) forproxy-respondents and 1.0 (95% CI = 0.4 to 2.1) for self-respondents. However, for NHL,OR's for self- and proxy-respondents were more similar for ever using 2,4-D or anyherbicides. Due to the presence of nondifferential and differential misclassification, a numberof the self- and proxy-respondent OR's were markedly different from each other. Thus, thefindings from this component indicated that pesticide data provided by proxy-respondents willnot necessarily result in the same estimate of risk or lead to the same conclusion as dataprovided by self-respondents.

Another component of this large methodologic study (39) examined the long-termreliability of reported pesticide information by reinterviewing, 7 to 10 years later, 389 self-respondents and 369 proxy-respondents from Minnesota who participated in the earlier Iowa-Minnesota case-control study of NHL and leukemia (18, 21). Percentages of agreement for first and second interview responses were higher for self-respondents than for proxy-respondents. For 2,4-D, agreement percentages ranged from 78 to 81% for self-respondents and from 59 to 73% for proxy-respondents. OR's and 95% CI's, calculated using data from the first and second interviews, were variable for both types of respondents. The disparities in the percentages of subjects exposed as reported in the first and second interviews had varying effects on the OR's. For leukemia, the self-respondent OR's did not differ much by interview; whereas, for NHL, there were some differences in the self-respondent OR's by interview. There were a number of differences in the proxy-respondent OR's by interview for both leukemia and NHL. The findings from this component showed that self- and proxy-respondents may not provide reliable information about past pesticide exposures due to nondifferential and differential exposure misclassification.

The final components of the large methodologic study (39) were to evaluate the short-term reliability and validity of reported pesticide exposure data. Short-term reliability was assessed by interviewing a sample of 157 farmers twice, 3 to 10 months apart. For 42 of the farmers who participated in the initial interview, validity was assessed by comparing the interview responses to data about 2,039 pesticide purchases collected from 14 local suppliers. The percentage of agreement was used to compare first and second interview responses provided by the farmers. The agreement of the farmers' responses in the first interview with the suppliers' records was evaluated by calculating the percentage of agreement, sensitivity, and specificity. The information from the suppliers was assumed to be the "gold standard".

More general pesticide exposure data (i.e., ever use) were reported reliably; whereas, more definitive pesticide exposure data (i.e., years of use, frequency of use, and duration of use) were reported less reliably. Agreement for ever use of any herbicides was 94%. For 2,4-D, the agreement percentage was 80%. Agreement percentages for 2,4-D for the average number of days used per year and the average number of hours used per day were 71 and 72%, respectively. As observed in this component of the study, the inability of respondents to reliably recall specific details of pesticide use is important because many of the positive associations between phenoxy herbicides and NHL reported to date have occurred among subgroups defined by frequency of exposure.

The validity of reported pesticide data was poor. The validity of pesticide use data is more critical than the reliability, because data may be repeatable, but inaccurate. For most pesticides, low values of sensitivity compared with those of specificity indicated that underreporting was a greater problem than overreporting; however, 2,4-D was a notable exception to this pattern. The overall agreement percentage for the farmers and suppliers was 81% for herbicides. In addition, the sensitivity was 89% and the specificity was 20%. For 2,4-D, the agreement percentage was 60%, the sensitivity was 63%, and the specificity was 53%. Findings from this component of the study demonstrated the potential for exposure misclassification and resulting errors in risk estimates for studies in which pesticide data are obtained by interview.

Epidemiology conclusion. In addition to the published reviews of the epidemiologic literature, a number of expert panels have weighed the evidence regarding the carcinogenicity of phenoxy herbicides, or 2,4-D alone. In 1987, a panel convened by the Canadian Centre for Toxicology (20) concluded that, "... there is limited evidence of carcinogenicity in man from exposure to phenoxy herbicides. In terms of exposure to 2,4-D specifically, the evidence must still be regarded as inadequate to classify it as a carcinogen." The International Agency for Research on Cancer Working Group reached the same conclusion for phenoxy herbicides (64). No distinction was made for 2,4-D. In 1989, a panel convened by the Harvard School of Public Health Center for Risk Analysis (35) concluded that, "Although a cause-effect relationship is far from being established, the epidemiological evidence for an association between use of 2,4-D and non-Hodgkin's lymphoma is suggestive and requires further investigation. There is little evidence of an association between use of 2,4-D and soft-tissue sarcoma or Hodgkin's disease, and no evidence of an association between 2,4-D use and any other form of cancer." Another panel sponsored by the Industry Task Force II on 2,4-D Research Data (49) concluded, "... the epidemiological studies provide, at best, only weak evidence of an association between 2,4-D and the risk of cancer." Finally, in 1993, a Special Joint Committee of the Science Advisory Board and the Scientific Advisory Panel of the EPA (64) judged that, "... at this time, the data are not sufficient to conclude that there is a cause and effect relationship between the exposure to 2,4-D and NHL."

In weighing the evidence, one must consider that the results of the epidemiologic studiesare only as good as the data on which they are based. In particular, OR's can be affected by differences in exposure misclassification for cases and controls. Thus, the reliability andvalidity of reported pesticide exposure data, and the comparability of such data obtained fromself- and proxy-respondents have been explored in methodologic studies.

Only one methodologic study, however, has demonstrated the effect of pesticide exposuremisclassification on the OR (39). Furthermore, this is the only study to systematicallyexamine the validity of pesticide exposure data, as well as to evaluate the short- and long-termreliability of such data. The combined results of this study demonstrated the potential for bothdifferential and nondifferential exposure misclassification and the potential for resulting errorsin risk estimates for studies in which pesticide data are obtained by interview. In particular,there was substantial evidence regarding the poor quality of reporting exposures to 2,4-D.

As a result, findings from the previously conducted case-control studies should not begiven much weight when determining whether there is a causal association between phenoxyherbicides, or 2,4-D, and cancer. At this point in time, the only conclusion that can be drawnfrom the epidemiologic studies is that the data are insufficient to assess the carcinogenicity ofphenoxy herbicides, or 2,4-D, in humans.

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TOXICOLOGY

Toxicology background. The chemical structure of 2,4-D allows it to mimic the plant hormone, indoleacetic acid (49). Because of it's structural similarity to this plant hormone, absorption of 2,4-D through roots and leaves can result in altered plant metabolism, abnormal growth, and plant death.

The results from a series of epidemiologic studies, described in the preceding section, raised questions about the safety of 2,4-D for humans (49). A number of toxicologic studies have been conducted in response to these safety concerns, and to fulfill the EPA requirements for re-registration of 2,4-D (36, 49). In 1992, the manufacturers of 2,4-D commissioned an extensive review of these studies, which was published in the Journal of the American College of Toxicology (49). This report was reviewed by a panel of nonindustry experts in toxicology and epidemiology. In addition, the Science Advisory Board of the EPA has issued a report that reviews the epidemiologic and toxicologic data on the potential carcinogenicity of 2,4-D (64). Data related to the carcinogenicity of 2,4-D also was reviewed by an expert panel convened by the Harvard School of Public Health (35).

This section of our review presents a summary and update of toxicologic studies relating to the health risk assessment of 2,4-D, drawn mainly from the reviews already mentioned, and from summaries of the data collected for submission to the EPA for the reregistration of 2,4-D (36). The results from some of the key toxicologic studies are presented in Table 4.

Environmental fate. In 1989, the World Health Organization published a review and evaluation of the environmental effects of 2,4-D (73). The general conclusion from this review was that 2,4-D does not persist in the soil because it is rapidly broken down and detoxified by light and by microorganisms in the soil (73). Because most organisms rapidly excrete 2,4-D, this herbicide would not be expected to accumulate or remain stored in the tissues of animals (73).

Contaminants. The purity of technical grade 2,4-D can range from less than 90% to 99% (72). The forms of 2,4-D most commonly used in forestry and agriculture are the alkali salts, amine salts, or esters (73). Technical grade formulations of 2,4-D may contain solvents or "wetting agents" that help the herbicide stick to and cover the plants (73). The presence of other types of impurities depends on the purity of the starting material, the procedure used to manufacture the specific form of 2,4-D, and the storage conditions (72).

Reactions that take place at high pH and high temperatures tend to increase the formation of polychlorinated dibenzo-*p*-dioxins (PCDD's), some of which are toxic (72). A study done by researchers at Agriculture Canada in the early 1980's tested samples of 2,4-D for the presence of PCDD's (23). The levels of PCDD's differed depending on the form of 2,4-D. Out of 11 samples of 2,4-D acid analyzed, none had levels of PCDD's above the detection limit of 1 ppb. By contrast, eight out of 26 samples of 2,4-D amine salts had detectable PCDD levels, which ranged from 5 to 587 ppb.

The samples of 2,4-D esters had the most widespread PCDD contamination. PCDD's were detected in 20 out of 21 samples of 2,4-D esters, with levels ranging from 35 ppb to 23.8 ppm. Another study, however, detected 6.8 ppb 2,3,7,8-TCDD in a German formulation of 2,4-D (27). The Canadian Government limits PCDD contamination of 2,4-D formulations to 10 ppb (49). In the United States, the technical product of each manufacturer is analyzed for the presence of PCDD's, and the health risk posed by the contaminants is evaluated on a case-by-case basis.[2]

Nitrosamines, which can be carcinogenic, have been detected in amine formulations of 2,4-D (72). Nitrosamines may form when 2,4-D amine salts are stored along with nitrates inmetal containers. Nitrates have been added to metal containers to prevent corrosion. Thechange in packaging of 2,4-D from metal containers to plastic or epoxy-lined containers wouldbe expected to eliminate the formation of nitrosamines (49).

Few studies rigorously address the toxicology of complex mixtures. Therefore, the effectof solvents, additives, or impurities on the toxicology of 2,4-D remains largely unknown. Onestudy found, however, that when rats were fed 2,4-D for 13 weeks, technical grade 2,4-D acid(97.3% pure) was no more toxic than purified 2,4-D acid (26).

Estimated exposure levels. The highest levels of exposure to 2,4-D occur in occupationalsettings. The amount of 2,4-D absorbed from occupational exposures will vary depending onthe type of work and on the type of safety measures used. It has been estimated that, withoutprotective gear, commercial applicators may be exposed to 2 to 160 g of 2,4-D/kg/day and forestry workers may be exposed to 0.86 to 129 g of 2,4-D/kg/day (49). Workers whospray herbicides from a backpack may receive some of the highest doses of 2,4-D. It has beenestimated that workers using backpack sprayers and wearing protective clothing had internaldoses ranging from 30 to 244 g/kg/day (49). The doses received by workers involved inaerial spraying have been estimated to range from 0.53 to 8.54 g/kg/day (49). One studyestimated that farmers who do not wear protective gear received an average dose of 5.78 g/kg of 2,4-D during eachspray operation.

A variety of surveys indicate that commercial foods and public water supplies do notpresent a significant source of exposure of 2,4-D to the general public (72). Duringapplication periods, the general population in herbicide use areas usually is not exposed to doses of 2,4-D greater than 2 g/kg/day (72). Likewise, the dose of 2,4-D received by home gardeners has been estimated to be less than 2 g/kg/day (49).

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[2] Personal communication. 1995. Stephen Funk, Chemistry Branch, EPA, Washington, D.C.

Absorption. Approximately 90% of exposure of agricultural workers to 2,4-D occurs through skin contact. The observation that 2,4-D can be detected in the urine 4 hours after dermal exposure suggests that 2,4-D is rapidly absorbed through the skin, and also rapidly excreted (49). Absorption of 2,4-D is slower through the skin than through ingestion. In addition, skin can serve as a reservoir for 2,4-D (49). The amount of 2,4-D absorbed through the skin depends on a number of factors, including the chemical form of 2,4-D, the condition of the skin, the site of dermal contact on the body, and the solvent in which 2,4-D is dissolved. For example, one study found that, when applied to the forehead of humans, approximately 58% of the applied dose of 2,4-D dimethylamine was absorbed in contrast to 6% of the applied dose of 2,4-D isooctyl ester (49). The interpretation of data from toxicity studies conducted in animals is difficult because the efficiency of absorption of 2,4-D varies across animal species. For example, whereas 2,4-D dimethylamine is absorbed relatively efficiently when applied to the foreheads of humans, only 20% of a dose of 2,4-D dimethylamine was absorbed when it was applied to the shaved backs of rats over the course of 7 days (49).

Exposure to 2,4-D through inhalation may occur in some occupational settings. Inhalation has been estimated to account for approximately 2% of exposure for applicators who spray 2,4-D (35). Inhalation may be a significant route of exposure for workers involved in the manufacturing of 2,4-D. Unfortunately, there is little research data on the absorption of 2,4-D through inhalation (49).

Absorption of 2,4-D appears to be rapid and complete from the gastrointestinal tracts of humans and experimental animals (49, 72). Although ingestion is usually a relatively minor route of exposure, most toxicity testing of 2,4-D has been conducted by oral exposure. Because 2,4-D is absorbed more efficiently through the gastrointestinal tract than through the skin, 2,4-D should be more toxic when ingested than when applied to the skin. Therefore, using oral studies of 2,4-D to test toxicity may add some margin of safety when these data are used to predict risk from exposure to 2,4-D through skin contact.

Distribution through the body. Following absorption, 2,4-D is distributed throughout the body (49). Studies conducted in a variety of species show that, after oral dosing, 2,4-D is found in the liver, kidney, lung, and to a lesser extent in the brain (49). The distribution of 2,4-D through the human body appears to be similar to that in test species. When organs were examined following fatal poisonings, the highest levels of 2,4-D were found in kidney and liver, with lower levels found in brain, muscle, and heart (72). It also has been reported that up to approximately 17% of a dose of 2,4-D can cross the placenta in pregnant mammals (72). Transport of 2,4-D into tissues and across the blood-brain barrier probably occurs by a cellular transport system, such as the organic acid transporter (49). Because 2,4-D is water soluble it is excreted in the urine, and does not tend to be stored or to accumulate in tissues in contrast to fat-soluble compounds (49).

Binding of 2,4-D to plasma proteins can occur and may affect distribution (72). When 2,4-D is bound to the plasma proteins, it cannot reach tissues where it might cause damage. High doses of 2,4-D can saturate or use up all of the plasma protein binding sites, which could result in a dramatic rise in the concentration of "free" 2,4-D. Free 2,4-D may be excreted. At very high doses of 2,4-D, however, the rate of excretion may slow down, and therefore the concentration of 2,4-D that can reach tissues in the body may increase and therefore cause toxicity. Exposure to high doses of other compounds that compete with 2,4-D for binding to plasma proteins may also cause in a rise in the concentration of free 2,4-D.

Excretion. All species studied, including humans, excrete 2,4-D mainly in the urine (72). The rate of excretion depends on the dose of 2,4-D. Excretion of 2,4-D is through the organic acid transport system in the kidney (49). Low doses of 2,4-D are excreted more rapidly than high doses, which can saturate this active kidney transport system. This phenomenon was demonstrated in a pharmacokinetic study of 2,4-D in rats, designed to measure the rate at which 2,4-D is absorbed and excreted (26). In this study, rats were given single oral doses of 14C labeled 2,4-D at 10, 25, 50, 100, or 150 mg/kg. The concentration of labeled 2,4-D in the plasma and the urine was measured 6 hours later. The rats given 100 and 150 mg/kg 2,4-D exhibited a dramatic increase in the plasma concentration of labeled 2,4-D compared with rats given the lower doses. The rats in the two high-dose groups also exhibited a corresponding decrease in urinary excretion of labeled 2,4-D. Munro et al. (49) point out that the doses of 2,4-D that most humans are exposed to should be below doses that saturate active kidney transport. Therefore, they suggested that toxicologic results from animals treated with high doses of 2,4-D that saturate renal transport should be interpreted with caution because they may not be relevant to typical human exposures (49).

Metabolism. Many compounds are broken down or transformed by specific enzymes present in almost all tissues, but present in especially high concentrations in the liver. Although this type of metabolism can detoxify chemicals, sometimes these enzymes transform a compound into a chemical that is even more toxic than the original one. Studies indicate that 2,4-D is not extensively metabolized in humans or other mammals, and furthermore 2,4-D does not appear to be transformed into a more toxic compound by metabolic enzymes (49). In one study, five male humans were given an oral dose of 5 mg/kg 2,4-D acid (57). This study reported that 2,4-D was efficiently absorbed and then eliminated. Half of the initial dose of 2,4-D was eliminated by 11.6 hours. Approximately 95% of the administered dose of 2,4-D was found eventually in the urine. Depending on the individual, from 0 to 12% of the 2,4-D found in the urine was in the form of conjugates, compounds that have undergone a specific detoxification reaction. Conjugates containing 2,4-D also have been identified in the urine of rats and pigs following oral exposure to 2,4-D. More toxic or reactive forms of 2,4-D, as a result of metabolism, have not been identified (49).

Acute toxicity. Acute toxicity usually refers to toxicity that occurs within a day or a few days after short-term, high dose exposure. Acute toxicity studies usually are intended to reflect a situation that would result in obvious poisoning. A common indicator of acute toxicity is the LD50, the dose that kills 50% of the test animals within a specified time interval. The lower the LD50, the more toxic the compound. The LD50 for 2,4-D varies depending on the form of the compound, the route of exposure (i.e., oral, skin, or inhalation), and the species to which it is administered. An early study determined an oral LD50 of 100 mg/kg in dogs, which appear to be the most sensitive species (72). A more recent study compared the oral LD50's of various forms of technical grade 2,4-D in rats (26). The test materials included: 2,4-D acid (95.0% pure), 2,4-D isoctyl ester (94.0% pure), 2,4-D dimethylamine salt (67.9% pure), 2,4-D isobutyl ester (96.1% pure), 2,4-D sodium salt (90.8% pure), 2,4-D butoxyethanol ester (97.1% pure), and 2,4-D butyl ester (98.6% pure). The LD50's ranged from 533 mg/kg for 2,4-D isobutyl ester in female rats (424 mg/kg 2,4-D acid equivalent) to 1090 mg/kg 2,4-D dimethylamine salt in male rats (619 mg/kg 2,4-D acid equivalent). Results from this study also indicate that acute exposure to 2,4-D through the skin is less toxic than acute oral exposure. The single dose dermal LD50's for all of the test materials was greater than 2000 mg/kg in rabbits. These results indicate that the acute dermal toxicity of 2,4-D is low.

The acutely toxic dose of 2,4-D in humans is difficult to determine. Death has resulted from ingestion of 80 mg/kg 2,4-D dimethylamine (72). An earlier report suggested that doses of 2,4-D as high as 36 mg/kg may not cause acute oral toxicity (72). In any case, workers should be able to avoid accidental exposure to acutely poisonous doses of 2,4-D through the use of proper occupational safety procedures.

Subchronic toxicity. Subchronic toxicity studies typically involve treating animals for approximately 3 months, and usually are intended to reflect a short-term exposure to a chemical. These studies usually report the highest experimental dose that does not cause toxicity, which is called the no-observed-adverse-effect-level (NOAEL). The NOAEL is an indication of a safe dose. These studies also usually report the lowest experimental dose that causes toxicity, which is called the lowest-observed-adverse-effect-level (LOAEL). Although most subchronic studies of 2,4-D have been oral studies, one subchronic study investigated the effects of dermal exposure to 2,4-D on both skin irritation and systemic (overall) toxicity (36). The results from this study support the conclusion from the acute study thintended to reflect a short-term exposure to a chemical. These studies usually report the highest experimental dose that does not cause toxicity, which is called the no-observed-adverse-effect-level (NOAEL). The NOAEL is an indication of a safe dose. These studies also usually report the lowest experimental dose that causes toxicity, which is called the lowest-observed-adverse-effect-level (LOAEL). Although most subchronic studies of 2,4-D have been oral studies, one subchronic study investigated the effects of dermal exposure to 2,4-D on both skin irritation and systemic (overall) toxicity (36). The results from this study support the conclusion from the acute study that dermal exposure to 2,4-D has low systemic toxicity. This study also demonstrated that the doses that

The 2 ethylhexyl ester and the dimethylamine salt of 2,4-D were significantly more irritating to the skin than was 2,4-D acid. The highest dose of 2,4-D acid, 1000 mg/kg/day, did not cause dermal irritation. These results indicate a NOAEL for this effect of 1000 mg/kg/day, but a LOAEL could not be determined. By contrast the LOAEL for dermal irritation for 2,4-D ethylhexyl ester was 162.5 mg/kg/day with a NOAEL of 16.3 mg/kg/day. The results for 2,4-D dimethylamine salt were similar, yielding a LOAEL for dermal irritation of 180.1 mg/kg/day with a NOAEL of 18 mg/kg/day. These results indicate that 2,4-D ethylhexyl ester and 2,4-D dimethylamine induce local effects on the skin at much lower doses than those required to cause systemic toxicity.

A subchronic oral study (26) conducted in rats compared the toxicity of purified 2,4-D to technical grade 2,4-D (97.3% pure). The rats were fed either purified or technical grade 2,4-D acid for 13 weeks at doses of 0, 15, 60, 100, or 150 mg/kg/day. No overt signs of toxicity or behavioral changes were noted during daily observations. Microscopic examination of nervous system tissue revealed no treatment-related effects. Significant treatment-related effects of other tissues included altered levels of the thyroid hormone tetraiodothyronine (T4), increased liver weights, and kidney lesions.

Females were more sensitive than males when effects of 2,4-D acid on body weight, levels of serum T4, and the liver were examined. Both males and females appeared to be more sensitive to purified 2,4-D acid than to the technical grade. The LOAEL for decreased body weight gain in females fed purified 2,4-D was 60 mg/kg/day, with a corresponding NOAEL of 15 mg/kg/day. The LOAEL for males was 100 mg/kg/day, with a NOAEL of 60 mg/kg/day. The LOAEL for decreased body weight gain for animals fed technical grade 2,4-D was 150 mg/kg/day for both males and females, with a corresponding NOAEL of 100 mg/kg/day. Both purified and technical grade 2,4-D appeared to cause a decrease in serum T4 levels in females, but not in males. The LOAEL for purified 2,4-D for was 60 mg/kg/day, and the NOAEL 15 mg/kg/day. The LOAEL for technical grade 2,4-D was 100 mg/kg/day, with a NOAEL of 60 mg/kg/day. Microscopic examination of thyroid tissue revealed no treatment-related changes. Purified 2,4-D acid caused an increase in relative liver weights in both males and females. The LOAEL for females for 2,4-D was 60 mg/kg/day, with a NOAEL of 15 mg/kg/day. The LOAEL for males was 150 mg/kg/day, with a NOAEL of 100 mg/kg/day. Technical grade 2,4-D caused an increase in relative liver weights in females, but not males. The LOAEL for females fed technical grade material was 150 mg/kg/day, with a NOAEL of 100 mg/kg/day. Microscopic examination of liver tissue revealed minor, nonspecific effects primarily in the 100 and 150 mg/kg/day dose groups fed either purified or technical grade 2,4-D acid.

In this study, the kidney appeared to be the most sensitive target organ. In contrast to the other effects of 2,4-D acid, males were more sensitive to kidney effects than females. A significant increase in relative kidney weight was observed in all dose groups of males fed either purified 2,4-D or technical grade 2,4-D. The LOAEL for increased kidney weight was 15 mg/kg/day, but no NOAEL could be determined. The LOAEL for females fed purified 2,4-D was 60 mg/kg/day, with a NOAEL of 15 mg/kg/day. The LOAEL for technical grade 2,4-D in this study was 150 mg/kg/day, with a NOAEL of 100 mg/kg/day. Microscopic examination of kidney tissue also revealed treatment-related changes in males and females. Changes in kidney tissue were more extensive at 60 mg/kg/day and higher doses where the authors predicted that 2,4-D would saturate active kidney transport. This study indicates a LOAEL of 15 mg/kg/day for oral subchronic exposure in rats based on effects on the kidney. A NOAEL could not be determined from this study.

More recent rodent studies indicate a NOAEL of 15 mg/kg/day for subchronic ingestion of 2,4-D.3 These studies, completed in 1991, examined the toxic effects of 1, 15, 100, or 300 mg/kg/day 2,4-D on rats or mice. The LOAEL for rats was 100 mg/kg/day based on histopathology, changes in body weight, and clinical pathology. The LOAEL in mice was 100 mg/kg/day based on decreased levels of glucose and T4, and increased kidney weights. The NOAEL for both rats and mice was 15 mg/kg/day.

Dogs appear to be more sensitive to the subchronic oral toxicity of 2,4-D toxicity than rodents (22). One dog study compared the toxicity of 2,4-D acid (96.7% pure), 2,4-D dimethylamine salt (66.7% pure), and 2,4-D 2-ethylhexyl ester (95.1% pure). Beagles were fed 2,4-D for 13 weeks at doses of 0, 1.0, 3.75, and 7.5 mg/kg/day. The 2,4-D acid also was given at an additional dose of 0.5 mg/kg/day for 13 weeks. No effects on hematology (blood), urinalysis, or ophthalmology were observed. All three forms of 2,4-D had significant effects on body weight gain, some parameters of clinical chemistry, and testes weight.

Although all three forms of 2,4-D caused a significant decrease in body weight gain, 2,4-D acid and 2,4-D 2-ethylhexyl ester appeared to be more potent than 2,4-D dimethylamine salt. The LOAEL for 2,4-D acid and 2,4-D 2-ethylhexyl ester was 3.75 mg/kg/day, and the NOAEL was 1 mg/kg/day. The LOAEL for 2,4-D dimethylamine salt was 7.5 mg/kg/day with a NOAEL of 3.75 mg/kg/day.

Dose-related effects were noted for 5 of the 17 clinical chemistry parameters examined. These included an increase in blood urea nitrogen (BUN), creatinine, and alanine aminotransferase; a decrease in alkaline phosphatase; and, in dogs treated with 2,4-D dimethylamine salt, an increase in aspartate aminotransferase. These results indicate a LOAEL of 1 mg/kg/day for 2,4-D dimethylamine salt and 2,4-D 2-ethylhexyl ester for changes in clinical chemistry. A NOAEL could not be determined. In the case of 2,4-D acid, the study established a LOAEL of 1 mg/kg/day for changes in alanine aminotransferase and creatinine, with a corresponding NOAEL of 0.5 mg/kg/day; and a LOAEL of 3.75 mg/kg/day for changes in BUN, with a NOAEL of 1 mg/kg/day. The authors state, however, that they did not consider these changes in clinical chemistry significant because they did not observe any treatment related microscopic changes in the kidney. In addition, progression in these effects was not observed in a chronic study of 2,4-D discussed below (22). Microscopic examination did reveal changes in the liver. The authors derived a LOAEL of 7.5 mg/kg/day and a NOAEL of 3.75 mg/kg/day for all three formulations based on liver effects.

Treatment with either of the three formulations resulted in a significant decrease in testes weight. The LOAEL for the effect of 2,4-D acid on testes weight was 3.75 mg/kg/day with a NOAEL of 1 mg/kg/day. The LOAEL for the 2,4-D amine and the 2,4-D ester was reported as 7.5 mg/kg/day with a NOAEL of 3.75 mg/kg/day. The authors did not observe significant treatment-related effects on the weights of other organs.

The authors concluded that these studies indicate a overall NOAEL of 1 mg/kg/day for subchronic ingestion or any of the three forms of 2,4-D. These data were reviewed by the EPA Office of Pesticide Programs, which concurred with the authors conclusion.[3] Collectively, these studies indicate a NOAEL of 1 mg/kg/day for subchronic ingestion based on dogs as the most sensitive species.

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[3] Personal communication. 1995. Jess Rowland, Office Pesticide Programs, EPA, Washington, D.C.

Chronic toxicity. The results from oral chronic (i.e., long-term) studies conducted on rats and dogs are consistent with the results from the subchronic studies (22, 36). First, these studies indicate that dogs are more sensitive to chronic toxicity of 2,4-D than rodents. Second, the chronic dog study also supports a NOAEL of 1 mg/kg/day for 2,4-D (22).

A chronic ingestion toxicity study of 2,4-D acid in dogs was designed based on the results from the subchronic study discussed previously (22). The authors only studied 2,4-D acid, based on their conclusion that the subchronic toxicity of 2,4-D acid is similar to that of 2,4-D dimethylamine salt and 2,4-D 2-ethylhexyl ester. Beagles were fed diets containing 0, 1.0, 5.0, or 7.5 mg/kg/day 2,4-D acid (96,7% pure) for a year. Consistent with the findings from the subchronic study, the authors detected no significant alterations in hematology or urinalysis. In addition, microscopic examination revealed no treatment-related effects on bone marrow, lymph nodes, or spleen.

Treatment-related effects included decreased body weights, changes in clinical chemistry, and effects on the kidney and liver. Treatment with 2,4-D resulted in a decreased body weight gain for females, but not males. The LOAEL for females was 7.5 mg/kg/day, with a NOAEL of 5 mg/kg/day. The NOAEL for males was 7.5 mg/kg/day, but a LOAEL could not be determined. Changes in some of the clinical chemistry parameters were noted in both males and females. Dose-related changes in clinical chemistry included decreased glucose levels, and increases in BUN, creatinine, cholesterol, and alanine aminotransferase. The LOAEL for these effects was 7.5 mg/kg/day for both males and females, with a NOAEL of 5 mg/kg/day. Microscopic examination revealed effects on the liver and kidney in both males and females in the 5 and 7.5 mg/kg/day dose groups. These results indicate a LOAEL of 5 mg/kg/day and a NOAEL of 1 mg/kg/day based on the liver and kidney effects. These data were reviewed by the EPA Office of Pesticide Programs, which concurred with the NOAEL of 1 mg/kg/day.3

The results of chronic rodent studies are similar to those of the dog study. A 2-year chronic oral study conducted in rats, completed in 1984, supports the NOAEL derived from the chronic dog study.3 The LOAEL from this study was 5 mg/kg/day, with a NOAEL of 1 mg/kg/day based on kidney effects. More recent rodent studies indicate that dogs are more sensitive to 2,4-D than rats. A chronic study conducted on rats indicates a LOAEL of 75 mg/kg/day for 2,4-D acid based on decreases in body weights, with a NOAEL of 5 mg/kg/day (36). This study is discussed later in our "Carcinogenicity" section. A chronic oral mouse study, also discussed under "Carcinogenicity," indicates a LOAEL of 150 mg/kg/day based on renal effects and a NOAEL of 5 mg/kg/day (36).

Collectively, these studies suggest an overall NOAEL of 1 mg/kg/day for chronic exposure to 2,4-D, based on the observation that dogs are the most sensitive species and that liver and kidney are the target organs. The NOAEL from the dog study is used to calculate the reference dose (RfD) for 2,4-D currently used by the EPA Office of Pesticide Programs. The RfD is an estimate of the dose that humans, including sensitive subpopulations, could be exposed to daily, throughout their lifetime without appreciable risk of toxic effects. The calculation of the RfD is discussed in the "Toxicology conclusion" section at the end of this chapter.

Neurotoxicity. Some case reports have suggested an association between exposure to 2,4-D and the development of nervous system effects ranging from peripheral polyneuropathy and reduced nerve conduction velocity to depression, anxiety, and other symptoms of post-traumatic stress syndrome in Vietnam veterans (49). In test animals, doses of 2,4-D above 100 mg/kg can cause myotonia of the skeletal muscle (49), and oral doses above 150 mg/kg of 2,4-D can damage the blood-brain barrier (46). Toxicologic studies in rats and rabbits indicate, however, that neurotoxic effects of 2,4-D do not occur below doses that saturate the kidney transport system. Therefore, neurotoxic effects would only be expected to occur at high doses of 2,4-D.

A short-term study conducted in rats investigated the neurotoxic effects of skin contact with 2,4-D (46). In this study, all four limbs of male rats were treated with a 12% or 24% solution of 2,4-D dimethylamine. The authors noted that when 2,4-D dimethylamine is used as an herbicidal spray it usually is diluted to final concentration of 0.5 to 2%. The rats were treated for 2 hours per day, 5 days a week. Treatment with 24% 2,4-D dimethylamine was stopped after 2 weeks because the animals developed severe dermatitis. Treatment with 12% 2,4-D dimethylamine was conducted for 3 weeks as planned, inasmuch as the animals exhibited only minimal skin change. The levels of 2,4-D measured in plasma were 323 g/ml after 2 weeks of treatment with a 24% solution, and 66.5 g/ml after 3 weeks of treatment with a 12% solution. The dramatic increase in plasma levels of 2,4-D at the higher dose was attributed to increased absorption through the damaged skin.

Dermal treatment with 2,4-D dimethylamine resulted in significantly decreased body weights and increased kidney weights, but no treatment-related effects on nervous system tissue (46). Decreased body weights were observed in animals treated with either 12% or 24% 2,4-D dimethylamine. Rats treated for 3 weeks with a 12% solution also exhibited an increase in kidney weights. Histology did not reveal any treatment-related effects on the kidney, suggesting that the increase in kidney weight may be an adaptive response to the active excretion of 2,4-D. One measure of neurotoxicity, grip strength, was increased after 3 weeks of treatment with a 12% solution. This result is consistent with other reports that indicate that 2,4-D can increase forelimb and hindlimb grip strength. The significance of the increased grip strength of the rats is not clear. Histology did not reveal any treatment-related lesions in central and peripheral nervous system tissues. This study indicates that short-term exposure to 2,4-D does not cause observable pathological effects on the nervous system.

To address the effects of prolonged exposure on the nervous system, the Industry Task Force II on 2,4-D Research Data conducted a 1-year oral neurotoxicity study on rats (36). Rats were fed diets providing 0, 5, 75, or 150 mg/kg/day of 2,4-D acid. The rats were evaluated by a functional observational battery (a series of observational tests to assess neurotoxicity), forelimb and hindlimb grip performance, landing foot splay, and an automated test of motor activity. Evaluation was conducted before exposure, and after 3, 6, 9, and 12 months of exposure. At the end of 12 months, central and peripheral nervous system tissues from the control and high dose group underwent microscopic examination.

A summary of the study results reported that the only significant neurological effects occurred in the high dose group. Retinal degeneration was noted in females treated with 150 mg/kg/day. Forelimb grip performance, normalized for body weight, was significantly increased in both males and females treated with 150 mg/kg/day. Systemic effects occurred at lower doses. Significantly decreased body weights were observed in the 75 and 150 mg/kg/day dose groups. The effect on body weight is consistent with the results of the rat subchronic study conducted by Gorzinski et al. (26). These results indicate a LOAEL of 150 mg/kg/day and a NOAEL of 75 mg/kg/day for neurotoxicity. This study also indicates a LOAEL of 75 mg/kg/day for a decrease in body weights, with a corresponding NOAEL of 5 mg/kg/day.

Reproductive and developmental toxicity. To examine the effects of 2,4-D on reproduction, the Industry Task Force II on 2,4-D Research Data conducted a two generation study in rats (36, 49). The rats were administered 0, 5, 20, or 80 mg/kg/day 2,4-D acid as a single dose from days 6 through 15 of gestation. The 80 mg/kg/day dose of 2,4-D caused excessive maternal toxicity, as indicated by reduced maternal body weights and food consumption. The high dose group also exhibited decreased length of gestation, and reduced live-litter size. In addition to the maternal toxicity observed in the high dose group, decreased pup weight was observed in the 20 mg/kg/day group. The LOAEL for reproductive effects was determined to be 20 mg/kg/day based on the decreased pup weight. The NOAEL for reproductive effects was 5 mg/kg/day.

Studies conducted in rats and rabbits indicate that 2,4-D does not cause birth defects or effect development (36). In one study, female Fischer 344 rats were administered 2,4-D acid via stomach tube once a day from days 6 through 15 of gestation. The dose range in this study was 0, 8, 25, or 75 mg/kg/day. No teratogenic or embryotoxic effects were observed at these doses. There was a decrease in maternal body weight gain, however, in the 75 mg/kg/day dose group. This study indicated a LOAEL of 75 mg/kg/day for maternal toxicity based on effects on body weight gain, with a corresponding NOAEL of 25 mg/kg/day.

Similar results were obtained from a study that investigated the potential developmental toxicity of 2,4-D triisopropanolamine, 2,4-D isopropylamine, and 2,4-D butoxyethyl ester (36). In this study, rabbits were administered 0, 10, 30, or 75 mg/kg/day acid equivalents of 2,4-D on days 7 through 19 of gestation. No treatment-related effects on embryo-fetotoxicity or teratogenicity were observed at any of the doses. Maternal toxicity was noted at 30 and 75 mg/kg/day for all three forms of 2,4-D. Maternal toxicity was indicated by a number of effects including decreased body weight gains, myotonia, and urine discoloration. This study indicates a NOAEL for maternal toxicity of 10 mg/kg/day, and a LOAEL of 30 mg/kg/day for all three forms of 2,4-D. These results indicate that rabbits are more sensitive to the general toxic effects of these forms of 2,4-D than to the general toxic effects of 2,4-D acid.

Carcinogenicity. The potential carcinogenicity of 2,4-D has been under review for over a decade. In August, 1980, the EPA requested that 2,4-D be tested for carcinogenicity in rats and mice (64). In 1987, the EPA classified 2,4-D under Group "D", "not classifiable as to human carcinogenicity," pending additional data (64). As previously discussed in the "Epidemiology conclusion" section, the Harvard School of Public Health convened a panel of 14 scientists (35) to, "...examine the weight of evidence on the potential carcinogenicity of 2,4-D." More recently, a public advisory group to the EPA, the Joint Committee of the Science Advisory Board and the Scientific Advisory Panel (SAB/SAP), met in 1993 to review the results from epidemiologic studies, carcinogen bioassays, and other relevant data concerning the potential carcinogenicity of 2,4-D (64). Both the SAB/SAP and the panel convened by the Harvard School of Public Health concluded that results from the rodent carcinogen bioassays available at the times of the reviews provided weak evidence that 2,4-D is carcinogenic (35, 64).

The SAB/SAP evaluated data from a variety of mutagenicity studies and concluded that 2,4-D does not appear to be mutagenic (64). The Ames test, mouse micronucleus assay, and unscheduled DNA synthesis assay were uniformly negative for various forms of 2,4-D. The SAB/SAP found that other types of mutagenesis assays that sometimes yielded positive results, such as tests of cytogenetics in human and animal lymphocytes, had significant experimental deficiencies. For example, 2,4-D was positive in some tests, but lacked a dose-response. Other reports of positive results did not specify the source and purity of the 2,4-D. These types of problems raised questions about the validity of the positive results. The SAB/SAP concluded that the available data suggests that 2,4-D is not genotoxic. The report from this committee also noted that although positive results would have strengthened the case that 2,4-D is carcinogenic, negative results do not necessarily mean that 2,4-D is not carcinogenic.

The SAB/SAP and the panel convened by the Harvard School of Public Health evaluated data from the same two rodent carcinogenicity studies. A 2-year feeding study conducted in B6C3F1 mice was completed in 1987. The mice were fed 0, 1, 15, or 45 mg/kg/day 2,4-D (35, 49). The study reported no excess tumors in males or females in any of the dose groups (35). A second 2-year feeding study conducted in Fisher 344 rats was completed in 1986 (35, 49). The rats were fed the same doses of 2,4-D as the mice (35). The dose range was chosen on the basis of a 13-week subchronic study, which indicated that 60 mg/kg/day of 2,4-D produces kidney damage. The results from this study indicated no statistically significant increase in tumors in female rats. In male rats, however, there appeared to be a statistically significant increase in the occurrence of a type of brain tumor, astrocytomas, in the high dose group. One astrocytoma was identified among the 60 controls, none were observed in the 1 and 5 mg/kg/day dose groups, two were observed among the 58 rats in the 15 mg/kg/day group, and five were identified among the 60 rats fed 45 mg/kg/day.

The incidence of astrocytomas in the male rats was considered weak evidence of carcinogenicity by criteria used to evaluate potent neurocarcinogens such as methyl nitrosourea (35, 41, 49). For example, inbred rodents have a variable rate of spontaneous brain tumor incidence. Although there is not as much information on the F344 rats as other inbred rodents, it has been argued that the increase in astrocytoma incidence in the 2,4-D study is within the range of incidences of spontaneous brain tumor development. In addition, rats treated with 2,4-D did not appear to have signs of brain toxicity, preneoplastic lesions, or early neoplastic proliferations. On the other hand, the EPA Health Effects Division Carcinogenicity Peer Review Panel questioned whether this study used an adequate dose range. They specifically questioned whether the highest dose used in the study was a maximum tolerated dose. The maximum tolerated dose is the highest dose that will not decrease the lifetime of the animal due to causes other than carcinogenicity. This dose typically causes an approximately 10% decrease in body weight. The maximum tolerated dose is usually the highest dose used in carcinogen bioassays. To establish whether the incidence of astroycytomas was treatment-related, EPA personnel requested that additional rodent carcinogenicity studies be conducted at higher doses of 2,4-D (35, 64).

Two additional rodent carcinogenicity studies with 2,4-D were completed in March of 1995. One study was conducted in Fisher 344 rats. In this study, male and female rats were administered 0, 5, 75, or 150 mg/kg/day 2,4-D for either 12 months (1Fisher 344 rats. In this study, male and female rats were administered 0, 5, 75, or 150 mg/kg/day 2,4-D for either 12 months (15 animals/sex/dose) or 24 months (50 animals/sex/dose) (37). No treatment-related i[1] mice. The mice were fed 1, 5, 150, or 300 mg/kg/day for up to 24 months. The mid and high doses were excessively toxic to males. Therefore, the male mice were terminated at 1 year, and the study was continued with only the females. No treatment-related increase in tumors in female mice were noted up through 2 years. These recent rodent carcinogenicity studies support the suggestion that 2,4-D alone is not carcinogenic.

Toxicology conclusion.

Carcinogenicity. Recent rodent carcinogenicity assays indicate that treatment with 2,4-D alone does not cause an increase in tumor development. In addition to being negative in standard carcinogenicity bioassays, 2,4-D also was negative in a rat liver model for tumor promoters (1). These results indicate that 2,4-D is not carcinogenic alone, and furthermore is not synergistic with known mutagenic carcinogens.

Noncarcinogenic effects. Studies of noncancer endpoints indicate that 2,4-D is not a developmental toxicant, and that 2,4-D does not cause neurotoxic effects below doses that saturate kidney transport. Dogs appear to be more sensitive to 2,4-D than rats with respect to general toxicity. This may be due to species differences in the capacity for excretion of 2,4-D.

The goal of most risk assessments for noncarcinogenic effects is the calculation of an RfD. An RfD is an estimate of the reference dose that humans, including sensitive subpopulations, could be exposed to daily, throughout their lifetime without appreciable risk of toxic effects. An RfD is calculated by dividing a NOAEL by an uncertainty factor. The NOAEL is usually obtained from the study with the most sensitive species and most sensitive target organ. The uncertainty factor is calculated by assigning numbers ranging from 1 to 10 to account for specific sources of uncertainty when using data from animal studies to estimate a safe dose for humans.

RfD (mg/kg/day) = NOAEL (mg/kg/day) Uncertainty factor

Because dogs appear to be the most sensitive species to 2,4-D, the RfD will be calculated using the NOAEL from the chronic ingestion study conducted on dogs (22). The NOAEL from that study was 1 mg/kg/day based on the liver and kidney effects. Using conventional risk assessment methods, an RfD for 2,4-D would be derived by dividing the NOAEL of 1 mg/kg/day by an uncertainty factor of 100. The uncertainty factor of 100 is calculated by multiplying an uncertainty factor of 10 to account for interspecies extrapolation by another uncertainty factor of 10 to account for sensitive subpopulations. This would yield an oral RfD of 0.01 mg/kg/day. This RfD is consistent with the RfD for 2,4-D currently listed on the EPA's Integrated Risk Information System (63). This RfD should also be adequate for skin exposure, because absorption of 2,4-D via ingestion is very efficient and more rapid than the absorption of 2,4-D through the skin.

SUMMARY

Collectively, the epidemiologic and toxicologic data show that 2,4-D is not likely to be carcinogenic in humans unless it is acting through an unknown mechanism that is not evident in animals. Based upon the calculated RfD and data from exposure studies, the general public should not experience toxic effects from exposure to 2,4-D. Because workers involved in the manufacture or application of 2,4-D may be exposed to levels above the RfD, appropriate protective equipment always should be used.

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Table 1.

Summary of key case-control studies of phenoxy herbicides and soft-tissue sarcomas (STS), non-Hodgkin's lymphoma (NHL), and Hodgkin's disease (HD).

First author,reference, and year	Cases, number, and type	Controls, number, and type	Years encompassed for cases	Type of interview	Odds ratio (95% Confidence interval)	
					Phenoxy herbicides	2,4-D specifically
Hardell (30) 1979.	52 STS, hospital-based.	208, General population.	1970-1977	Mail with telephone supplement.	5.3(2.4 - 11.5)	---
Eriksson (25) 1981.	110 STS, population-based.	220, General population.	1974-1978	Mail with telephone supplement.	6.8 (2.6 - 17.3)	---
Smith (58, 59) 1984.	82 STS, population-based.	92, Other types of cancer.	1976-1980	Telephone.	1.3a (0.7 - 2.5)b	---
Hoar (34) 1986.	133 STS, population-based.	948, General population.	1976-1982	Telephone.	1.4c (---)d	1.3c (---)d
Smith (60) 1986.	51 STS, population-based	315, Other types of cancer.	1981-1982	Telephone.	0.7a (0.3 - 1.5)b	---
Vineis (65) 1986.	68 STS, population-based.	158, General population.	1981-1983	In-person and mail.	2.4e (0.6 - 10.3)b and 1.1f (0.2 - 5.1)b	--- 1.1f
Woods (70, 71) 1987.	128 STS, population-based.	694, General population.	1981-1984	In-person.	0.9g (0.4 - 1.9)	---
Hardell (33) 1988.	54 STS, population-based.	311, General population and 179, other types of cancer.	1978-1983	Mail with telephone supplement.	3.3h (1.4 - 8.1) and 2.2a (0.9 - 5.3)	---
Smith (61) 1992.	30 STS, hospital-based.	82, General population	1976-1987	In-person.	0.8h (0.2 - 3.7) and 2.5a	---

		and 82, other types of cancer.			(0.5 - 12.9)	
Hardell (32) 1981.	169 HD and NHL, hospital-based.	338, General population.	1974-1978	Mail with telephone supplement.	4.8 (2.9 - 8.1)	---
Hoar (34) 1986.	121 HD, population-based.	948, General population.	1976-1982	Telephone.	1.0c (---)d	1.0c (---)d
Hoar (34) 1986.	170 NHL, population-based.	948, General population.	1979-1981	Telephone.	2.2 (1.2 - 4.1)	2.3 (1.3 - 4.3)
Pearce (53) 1986.	83 NHL, population-based.	228, General population and 168, other types of cancer.	1977-1981	Telephone.	1.1h (0.6 - 2.2)b and 1.3a (0.7 - 2.2)b	---
Pearce (54) 1987.	183 NHL, population-based.	338, Other types of cancer.	1977-1981	Telephone.	1.0a (0.7 - 1.5)b	---
Persson (56) 1989.	54 HD, hospital-based.	275, General population.	1964-1986	Mail.	3.8 (0.7 - 21.0)b	---
Persson (56) 1989	106 NHL, hospital-based.	275, General population.	1964-1986	Mail.	4.9 (1.3 - 18.0)b	---
Woods (70, 71) 1989.	576 NHL, population-based.	694, General population.	1981-1984	In-person.	0.9 (0.5 - 1.5)	0.7 (0.4 - 1.3)
Zahm (74) 1990.	201 NHL, population-based.	725, General population.	1983-1986	Telephone.	Similar to risk estimate for 2,4-di	1.5 (0.9 - 2.5)
Cantor (21) 1992.	622 NHL, population-based.	1245, General population.	1980-1983	In-person.	1.2 (0.9 - 1.6)	1.2 (0.9 - 1.6)
Smith (61) 1992.	52 HD and NHL, hospital-based.	82, General population and 82, other	1976-1987	In-person.	0.8h (0.3 - 2.2) and 1.8a (0.5 - 6.0)	---

		types of cancer.				

[a] Odds ratio calculated using cancer controls.
[b] 90% confidence interval.
[c] Results not reported in original article. As cited by Blair et al. (7, 8).
[d] Confidence interval not provided.
[e] Odds ratio calculated using self-respondent subjects.
[f] Odds ratio calculated using next-of-kin for subjects.
[g] High exposure.
[h] Odds ratio calculated using population-based controls.
[i] Numeric results not reported in original article.

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Table 2. Summary of key cohort studies of phenoxy herbicides and soft-tissue sarcomas (STS), non-Hodgkin's lymphoma (NHL), and Hodgkin's disease (HD).

First author, reference, and year	Cohort population, number and type	Comparison population	Years of follow-up	Relative risk (95% Confidence interval)		
				STS	HD	NHL
Coggon(24) 1986	5,754 Phenoxy herbicide manufacturers and applicators.	England and Wales general population.	1947-1983	1.1 (0.0 - 5.9)	0.3 (0.0 - 1.6)	0.4 (0.0 - 1.3)
Ott (52) 1987	2,187 Phenoxy herbicide manufacturers.	U.S. general population.	1940-1982	2.5[a] (0.1 - 13.9)	0.9[a] (0.0 - 5.1)	1.9 (0.6 - 4.5)
Bond (15) 1988	878 2,4-D manufacturers.	U.S. general population and internal referents.	1945-1982	None observed.	2.7[b] (0.0 - 14.7)	3.9[b] (0.4 - 14.1)
Wiklund (66, 67, 68) 1989	20,245 Applicators.	Sweden general population.	1965-1984	0.9 (0.4 - 1.9)	1.5 (0.8 - 2.4)	1.1 (0.7 - 1.6)
Bloemen (14) 1993	878 2,4-D manufacturers.	U.S. General population and internal referents.	1945-1986	None observed.	Not reported.[c]	2.0[b] (0.2 - 7.1) and 3.0d (0.8 - 11.9)
Lynge (43, 44, 45) 1993	4,461 Phenoxy herbicide manufacturers, of which 2,119 were potentially exposed.	Denmark general population.	1947-1987	2.3[e] (0.6 - 5.8)	--	1.3[e] (0.4 - 3.3)

[a] Relative risk not reported in original article. As cited by Blair et al. (7, 8).
[b] Relative risk calculated using general population as comparison group.
[c] One case of HD had been observed in initial study (15), but was not reported separately in update.
[d] Relative risk calculated using internal referents as comparison group.
[e] Among cohort members with potential exposure to phenoxy herbicides._

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Table 3.

Summary of completed studies on the reliability and validity of pesticide use data obtained from interviews.

First author, reference, and year	Study population	Comparison population	Study type	Methods used	Major findings	Notes
Hardell (30) 1979	STS[a] cases and controls.	Employers.	Validity.	Contacted employers of subjects who had worked in forestry, sawmill, or pulp industries to corroborate reported exposures to phenoxy herbicides and chlorophenols; information obtained via mailed questionnaires.	Agreement good for chlorophenols.	Methods not clearly defined; low employer response rate; reliance on memories of employers; employers may not be "gold standard"; no data provided fc overall level of agreement or specifically for cases and controls; reporting differences for cases and controls not assessed.
Hoar (6, 12, 13, 34) 1986	STS, HD[b], and NHL[c] cases and controls.	Suppliers.	Validity.	Contacted suppliers for 110 subjects who had farmed to corroborate reported exposures to herbicides and insecticides; information obtained via in-person interviews with suppliers and records	Overall agreement for use of pesticides was about 50%; agreement better for the last 10 years; suppliers usually reported less pesticide use than subjects; overall agreement for herbicides was about 60%, but was lower for years used; agreements for	Methods not clearly defined; unclear as to which pesticides were assessed fc agreement; reliance on memories of suppliers; suppliers may nc be "gold standard"; recalculated OR not provided for 2,4-D; only limited data

				of suppliers.	herbicides was similar for cases and controls; recalculated OR[d] for NHL and herbicide use was higher; agree-ment for 2,4-D was 83% for NHL cases and 74% for controls.	provided in several publications.
Woods (70) 1987	STS and NHL cases and controls.	Supervisors and coworkers.	Validity.	Contacted supervisors and coworkers of subjects who had jobs with potential exposures to corroborate reported exposures to phenoxy herbicides, chlorophenols, and other chemicals; information obtained via telephone interviews.	Agreement obtained in essentially all instances in which supervisor or coworker was reached; agreement similar for cases and controls.	Methods not clearly defined; agreement assessed mostly for recent jobs; reliance on memories of supervisors and coworkers; supervisors and coworkers may not be "gold standard"; supervisor and coworker response rate nc provided; no dat provided for overall level of agreement or specifically for cases and controls.
Brown (19) 1991	Controls for NHL and leukemia cases.	Proxies.	Comparability of data from self- and proxy-respondents.	Interviewed 95 controls who had farmed and their proxies about controls' use of specific pesticides reported by the controls in earlier case-	Agreement about 95% for 2,4-D use; agreement better for more recent time periods; proxy-respondents reported more subjects as exposed than the subjects themselves;	Respondents asked only abou frequently used pesticides reported in earli study; could not assess reporting differences between cases and controls.

				control study.	agreement percentages for days per year of use for herbicides and 2,4-D specifically were about 50%.	
Boyle (17) 1992	STS, HD, NHL, liver, nasal, and nasopharyngeal cancer cases.	Proxies.	Comparability of data from self- and proxy-respondents.	Interviewed 270 proxies, for those cases who died during 4-year study period, about cases' use of pesticides, herbicides, and phenoxy herbicides containing 2,4-D.	For herbicides used in farming, sensitivity was about 45% and specificity was about 95%; for phenoxy herbicides containing 2,4-D, sensitivity was 35% and specificity was 100%.	Could not assess reporting differences between cases and controls.
Johnson (39, 40) 1993	NHL and leukemia cases and controls.	Proxies.	Comparability of data from self- and proxy-respondents.	Interviewed 328 proxies, for those cases and controls who died or became incompetent following interview in earlier case-control study, about use of pesticides, herbicides, and specific herbicides such as 2,4-D.	Agreement percentages for use of herbicides ranged from about 70 to 80%; for use of 2,4-D, agreement percentages ranged from about 60 to 75%; for both NHL and leukemia, OR's for herbicides and 2,4-D specifically were higher for proxy-respondents then self-respondents.	Proxy-responde interviewed several years aft self-respondents
Johnson (39) 1993	NHL and leukemia cases and controls.	Same.	Long-term reliability.	Reinterviewed 758 cases and controls from earlier case-control study about use of	Agreement percentages for 2,4-D use were about 80% for self-respondents and between 55 and 75% for	Reinterviews conducted up to decade after initial interviews

				pesticides, herbicides, and specific herbicides such as 2,4-D.	proxy-respondents.	
Johnson (39) 1993	Farmers.	Same.	Short-term reliability.	Interviewed 157 farmers on 2 occasions, less than 1 year apart, about use of pesticides, herbicides, and specific herbicides such as 2,4-D.	Agreement for use of herbicides was 94%; agreement for 2,4-D use was 80%; agreement for usual days per year of 2,4-D use was 71%.	Could not assess reporting differences between cases and controls.
Johnson (39) 1993	Farmers.	Suppliers.	Validity.	Abstracted data related to 2,039 pesticide purchases from 14 suppliers for 42 farmers to corroborate reported exposures to pesticides, herbicides, and specific herbicides such as 2,4-D.	Agreement, sensitivity, and specificity for herbicides were 81, 89, and 20%, respectively; for 2,4-D specifically, agreement was 60%, sensitivity was 63%, and specificity was 53%.	Suppliers may not be "gold standard"; could not assess reporting differences between cases and controls.

[a] Soft-tissue sarcoma.

[b] Hodgkin's disease.

[c] Non-Hodgkin's lymphoma.

[d] Odds ratio.

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Table 4.

Summary of NOAEL's[a] and LOAEL's[b] from key toxicity studies of 2,4-D.

Study type, species, and reference	Form of 2,4-D	NOAEL(mg/kg/day)	LOAEL(mg/kg/day)	Notes
21-day dermal, >toxicity, rabbit (36)	acid	1000	---	Systemic toxicity.
	1000	---	Dermal irritation.	
	2-ethylhexyl ester	1627.5	---	Systemic toxicity.
		16.3	162.8	Dermal irritation.
	dimethylamine	540.5	---	Systemic toxicity.
		18	180.1	Dermal irritation.
>				
13-week oral, toxicity, rat (26)	acid, purified	---	15	Kidney effects.
	acid, technical grade	---	15	Kidney effects.
Subchronic oral, toxicity, rat [c]	acid	15	100	Histopathology, body weight, and clinical pathology effects.
Subchronic oral, toxicity, mouse[c]	acid	15	100	Decreased glucose and T_4 levels and increased kidney weights.
13-week oral, toxicity, dog (22)	acid (96.7% pure)	1	3.75	Testes, body weight, clinical chemistry, and liver effects from all three forms.
	dimethylamine (66.7% pure)	1	3.75	
	2-ethylhexyl ester (95.1% pure)	1	3.75	
1-year oral, toxicity, dog (22)	acid	1	5	Liver and kidney effects.
2-year oral, toxicity, rat[c]	acid	1	5	Kidney effects.

2-year oral, toxicity and oncogenicity, rat (36)	acid	5	75	Decreased body weight, no indication of oncogenic effects.
2-year oral, oncogenicity, female mouse (36)	acid	5	150	Kidney effects, no treatment-related increases in the incidence of neoplasms.
1-year oral, neurotoxicity, rat (36)	acid	5	75	Decreased body weight.
		75	150	Retinal degeneration.
Two-generation oral, reproductive toxicity, rat (36, 49)	acid	5	20	Decreased pup weight.
Gavager[d], developmental toxicity, rat (36)	acid	25	75	Maternal toxicity. No teratogenic or embryotoxic effects observed.
Gavage, developmental toxicity, rabbit (36)	acid	30	90	Maternal toxicity for all four forms. No developmental effects observed for all four forms.
	triisopropanolamine	10	30	
	isopropylamine	10	30	
	butoxyethyl ester	10	30	

[a] No-observed-adverse-effect-level, which is the highest experimental dose that does not cause toxicity.
[b] Lowest-observed-adverse-effect-level, which is the lowest experimental dose that causes toxicity.
[c] Personal communication, Jess Rowland, Office of Pesticide Programs, EPA. 1995.
[d] Stomach tube.

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Chapter 4

Potential Economic Effects of Banning Phenoxy Herbicides in the United States

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Abstract. An assessment was undertaken to determine the possible economic impacts of the loss of either 2,4-D or all phenoxy herbicides in agricultural and non-agricultural uses in case of a regulatory ban. About 55 million pounds of phenoxy herbicides were used during 1992 in the United States with 2,4-D comprising 86% of total use or about 47 million pounds of acid equivalent. The severest economic effects from banning phenoxy herbicides would be felt in major field crops, rangeland, pastureland, and alfalfa used for forage. The total loss of phenoxy herbicides in these major uses only could result in net societal losses approaching $1.35 billion, which combine producer and consumer effects of yield, cost, and price changes. A total phenoxy herbicide loss scenario would result in the following yield losses: peanut (13%), flax (6.7%), sugarcane (5.7%), greenpea (5.6%), alfalfa (5.2%), asparagus (4.9%), barley (3.8%), sorghum (2.4%), and wheat (2.2%). Other major impacts include a loss of $367 million in turfgrass, $284 million in small grain production, $180 million in increased costs of noxious weed control, and $111 million in the production of orchard, vineyard, soft fruit, and nut crops. The estimated aggregate economic impact of losing only 2,4-D in the United States is a loss of $1.68 billion. If all uses of phenoxy herbicides were cancelled the net societal loss would be $2.56 billion. These estimates describe the yield and financial impacts of the initial production year after a phenoxy herbicide cancellation. Subsequent year's losses and financial impacts probably would be less as both farmers and markets adjust to the new production situation.

INTRODUCTION

This economic summary chapter provides a synopsis of the potential economic impacts of a phenoxy herbicide ban to United States agriculture and to non-agricultural users of phenoxy herbicides. Included are estimates of treated acreage in major and minor field crops, aquatics, vegetables, orchards, vineyards, soft fruit and nut crops, pastureland, rangeland, fallowed land, rights-of-way, noxious weed control, forestry, and turfgrass. Production and cost changes under a regulatory ban were estimated, as were changes in producer and consumer surplus values; potential commodity price fluctuations given price elasticity of demand estimates; changes in yield; and changes in aggregate commodity production. For some noncrop production uses, the cost of alternative measures of weed control was the only measure used to estimate the economic impacts. In other noncrop cases, estimates of potential economic losses to the farmer or rancher were made based on research results documenting specific components of expected impacts.

The economic analysis is based on a questionnaire (Appendix 1) sent in early 1993 to public weed scientists in 50 states plus Puerto Rico. State weed scientists selected by the assessment team then identified and enlisted the help of individuals considered experts in specific commodities within each state. These experts were asked for the following information: (a) estimates of acreage treated with 2,4-D and other phenoxy herbicides on a specific crop, commodity, or use; (b) alternative herbicides that potentially would be used including percent of treated acres having alternatives applied if either

2,4-D or all phenoxy herbicides were banned; (c) the potential yield effects of possible bans considering the availability of alternatives; (d) average application rates, timing, and number of treatments of phenoxy herbicides and alternative herbicides; (e) the identification of non-chemical weed control methods and estimated percent of acres currently being treated with phenoxy herbicides upon which these methods would be used; and (f) reasons to retain the phenoxy herbicides.

ESTIMATION OF CONSUMER AND PRODUCER SURPLUS

Estimating the effects of a pesticide regulatory action on producer and consumer surplus measures requires making assumptions about the effect on demand and supply curves resulting from some abrupt change in the existing state of the world. The concept of societal or social effects incorporates both producer and consumer surplus, which describe both economic efficiency and income distribution. Producer surplus, as used in this assessment, is the economic profit to producers of the crop affected by a pesticide restriction. Consumer surplus describes the willingness of consumers to pay for the affected crop. The economic implications of either a 2,4-D or a total phenoxy herbicide cancellation resulting in higher production cost and lower yield for a particular crop are described in Figure 1. The following discussion is paraphrased from Goodwin (3) as described in Barse, et al. (1).

Let DDemand be the demand function and SSupply0 the supply function of the crop affected by a regulatory action against a pesticide used during crop production. The price Pb and the quantity Qb represent the base year equilibrium condition. Assume a pesticide suspension or cancellation causing pest control costs to increase and yields of the affected crop to fall. The effect is demonstrated by the upward shift in SSupply0 to SSupply1 with a new equilibrium position at the higher price Pa and lower output Qa.

At the initial equilibrium position PbQb, prior to the pesticide suspension or cancellation, total revenue from the sale of the affected crop is the area bounded by PbQb, or area e+f+g+h+I. The initial short term production cost including a normal profit to growers is measured by the area h+I. The initial economic profit or surplus accruing to producers is e+f+g. The effects of a regulatory action against a pesticide are assumed to increase production costs and in some cases decrease the effectiveness of pest control by forcing producers to use materials that are more expensive or less effective or both. With higher costs and lower yield, the change in producer surplus is the change in total revenue, area b+c-g-I, minus the change in total cost, area c+f-I, or the area b-f-g. The change in producer surplus may be positive or negative depending on the price elasticities (the measure of responsiveness to price and quantity changes) of the demand and supply curves.

Consumer willingness to purchase output Qb is the entire area under the demand curve up to Qb, or area a+b+...+h+I. At equilibrium market price Pb consumers are obliged to pay only area e+f+g+h+I. The net benefit of maintaining the pesticide in use is area a+b+c+d. Cancellation results in a loss of consumer surplus measured as the area -(b+c+d).

The price of the primary commodity, affected by a pesticide regulatory action, as well as substitute commodities, whose prices may also change in response to the supply change of the primary commodity, affects both producer and consumer surplus. Suspending or cancelling a pesticide use may affect prices of commodities not directly involved but which have substitute or complimentary relationships. These indirect price effects may lessen the net societal effect. Both the direct and indirect price changes drive the total change in societal effects. The effect on society is defined as the change in producer surplus plus the change in consumer surplus, or area c+d+f+g in Figure 1. This area reflects the redistribution of income or the redistribution of purchasing power among individuals affected by both direct and indirect price changes.

Using pest control alternatives to a suspended or cancelled pesticide generally results in a transfer of income from consumers to producers through a higher price in response to lower yield and lower output in the short term. Producers who are not users of the cancelled pesticide would benefit by the higher crop price with no production cost effects.

Pesticide suspensions and cancellations will likely result in short term change in net societal effects through a redistribution of income between producers and consumers. When non-user producers gain, user-producers are likely to lose depending on the demand and supply elasticities associated with a specific crop.

METHODOLOGY

The potential economic effects of a regulatory action against the use of either 2,4-D or all phenoxy herbicides in major field crops and small grain crops were estimated using an econometric simulation model entitled AGSIM (8). The AGSIM model forecasts major field crop supply and demand dynamics given estimated crop yield and production cost changes resulting from a change in regulatory policy or other influence external to the model. The AGSIM model estimates prices, production, and acreage of corn, soybean, wheat, sorghum, oat, barley, peanut, alfalfa, and rice in major production regions for three 5-year periods extending into what is termed the "far future". These periods include 1996 through 2000, 2001 through 2005, and 2006 through 2010. For purposes of the present assessment, we assumed that a regulatory restriction of the phenoxy herbicides would be initiated in late 1995 with economic effects being evident in the 1996 crop year and then continuing through to 2000. Therefore, we used only the near term results for assessment purposes. AGSIM computes crop income changes and consumer gains and losses from input data describing yield and cost changes as estimated by commodity experts. As described earlier, changes in consumer surplus result from commodity price movements in response to aggregate yield effects. Losses in consumer surplus occur when supply is diminished and prices increase, assuming a stationary demand curve. Gains occur when commodity prices decrease as a result of increased acreage and subsequent supply. Producer surplus declines when yield decreases are proportionally greater than subsequent positive price response leading to net losses in revenue. Gains in producer surplus occur when the opposite holds true. The net aggregate effect for a particular commodity is the sum of the producer and consumer effects.

The AGSIM model is unique in that supply and demand relationships among crops are linked in a recursive adjustment process. When the costs of production or per acre productivity in a particular commodity are altered in a simulated year, the expected profits for that commodity relative to the others in the model are also altered, inducing shifts in planting decisions for the coming year. Crop acreage functions determine the proportion of total planted acreage allocated to each crop in each region. All planted acres must be distributed among crops including acres designated for the Conservation Reserve Program (CRP). The individual crop production functions along with calculated distribution of acreage among crops determine regional production which is then summed to arrive at national production estimates. Total supply is production plus inventories. National demand for individual crops is calculated using estimated crop prices and prices of substitutes and includes a time factor to account for dynamic market activity. Equating supply and demand allows estimation of excess demand equations, whose subsequent solution determines market prices and use patterns for the included commodities. Simulated crop prices, total production, and production costs allow the determination of regional crop-specific profit levels, which link simulated marketing years.

Market determined prices are inputs to the acreage response functions for the following year. The AGSIM model is discussed in greater detail by Taylor (7), Penson and Taylor (6), Osteen and Suguiyama (5), and Osteen (4).

The economic effects of a ban of either 2,4-D or all phenoxy herbicides for commodities other than the field and small grain crops included in AGSIM were estimated using both survey and existing data describing current 2,4-D and other phenoxy herbicide usage; estimated use of alternative chemical herbicides and non-chemical weed control methods if either 2,4-D or all phenoxy herbicides were banned; and estimated per acre cost and yield changes that would be incurred using alternative weed control methods. The yield losses and cost changes for individual crops are average values for acres treated with phenoxy herbicides. These estimates were applied to average acreage, production and prices for the years 1989 to 1991 as reported in Agricultural Statistics 1992 (9). For some fruit crops, acreage in production was taken from the 1987 Census of Agriculture United States (10). Economic effects include estimated changes in crop prices, production, and producer income; changes in consumer surplus as a result of shifting supply functions and subsequent price response; and the net economic effect, which sums the net producer and consumer effects and represents the net societal effect of a pesticide ban.

The estimates for commodities outside the AGSIM model are necessarily static as they do not account for changes in acreage, input substitution, or the effect of importation in response to price, yield, and cost changes. For these reasons the estimates for commodities outside the AGSIM model should be viewed as possible short term effects of a regulatory action.

For commodities that are not included in the AGSIM model the economic effects of a ban of either 2,4-D or all phenoxy herbicides were estimated using the following formulas as developed by Osteen (4):

Percentage change in farm level commodity price: N = Y/E where N is the percentage price change, Y is the percentage reduction in crop output, and E is the price elasticity of demand.

Change in production cost: C = DAB/100 where C is change in total cost, A is the percent of acres treated with the herbicide in question, D is the change in cost per treated acre, and B is total acreage.

Consumer effect: CE = (Pb-Pa)(Qa+Qb)/2 where CE is the consumer effect; Pb is the average market price before the herbicide ban; Pa = Pb(1+N/100), the price after the ban; Qb is the quantity produced before the ban; and Qa = Qb[1-(Y/100)] is the quantity produced after the ban.

Change in net revenue: DNR = PaQa-PbQb-C-FG, where DNR is the change in net revenue, F is the quality discount in price, and G is the quantity downgraded.

Net Effect: CE+DNR

For some commodities price elasticity of demand estimates were not available. In those instances the net effect is estimated as the value of yield loss plus the change in cost of alternative materials assuming a constant price: Pb(Qa-Qb)-C-FG. Without an estimate of price change a determination of producer and consumer effects is not possible, except under the circumstance where the commodity price is assumed to be constant in spite of a change in production. When this is the case, the effect on producers approximates the net effect. There are a number of instances in the analysis where this assumption was used to allow an approximation of potential producer impacts.

A number of factors can, in the longer run, influence the price and ultimately the net societal effects associated with regulatory actions against herbicides used in the production of specific commodities. For instance, the new trade arrangements under the North American Free Trade Agreement (NAFTA) and the culmination of the Uruguay round of the General Agreement on Tariffs and Trade (GATT) leading to the creation of the World Trade Organization have, in many cases, eliminated trade barriers to foreign producers of agricultural commodities thus freeing access to the United States market. For the agricultural commodities that are affected, the supply-induced pressure on crop prices caused by a regulatory action will be mitigated by the availability of imported stocks. However, while consumer prices may be maintained by new supply sources, the negative economic impacts on domestic producers remain. Expanded acreage in regions where the subject herbicides are not used, quantities of crops in storage, and world price pressures for commodities marketed globally will also tend to moderate price changes. In addition, consumer preferences may change, causing a shift in the demand curve for a particular commodity and altering producer and consumer surplus accounting. To account for these effects in crops outside the AGSIM model, the assumption was made that crop prices remain stable after the initial change in response to a change in production. This reduces the overall economic impact and concentrates the loss on the grower.

The differing effects of a regulatory action against either 2,4-D or all phenoxy herbicides are estimated for both treated and untreated acres. This demonstrates the inequities in terms of financial impact on users and nonusers of a targeted herbicide. While diminished yield on treated acres may or may not lead to commodity price increases at the national level, the cost of alternative control as well as the actual losses incurred by users of a targeted herbicide can result in substantial financial losses to those users. The following computations allow this important distinction to be made:

Treated acres: (Pa-Pb)Yb+Pa(Ya-Yb)-D-Fg, where Yb is yield per acre before the ban, Ya is yield after the ban, and g is the quantity downgraded per acre, and other terms as defined earlier.

Untreated acres: (Pa-Pb)Yb

The response to the questionnaire was comprehensive for the most important uses of the phenoxy herbicides. Coverage of greater than 90% of planted or harvested acres was the greater than 90% of planted or harvested acres was the general case for most commodities. In instances where less than 90% of national acres in a commodity were represented in the survey, assessment team members provided estimates of phenoxy herbicide use in significant missing states. The data were then extrapolated to reflect estimated use on 100% of acreage in a particular commodity. The crops for which this method was used are identified in individual commodity chapters. Finally, for some noncrop production uses of phenoxy herbicides, economic impacts include estimates of potential loss to the value of the natural resource being protected from weed incursion. For instance, in the rangeland and pastureland applications, the research literature indicate significant dollar losses in the value of forage if weeds are not controlled in some manner. Both the amount and quality of the forage is diminished. This report assigns a dollar value to that los

Accuracy of the Economic Estimation Process. There are a number of possible sources of error in the economic impacts estimation process. The survey process is predicated upon expert opinion, which seeks to elicit the collective expertise of recognized authorities in a particular discipline to provide information based on hypothetical situations; specifically, estimates of yield loss given alternative scenarios of herbicide availability. Experts are asked to make estimates based upon published research which has dealt with the relation between the commodity and pesticide in question. In many states the actual extent of use of a specific herbicide on a particular commodity was not known. Furthermore, the economic variables are a source of variation and therefore error. For instance, pesticide prices may vary somewhat by region and also within a particular region depending upon the buying power of the farmer. The majority of the prices used in the analysis are from *AGCHEMPRICE 1993* (2) and represent national average prices for specific active ingredients. In some instances state extension personnel were contacted to augment published prices. Discrepancies in pesticide prices would impact the cost of alternative herbicide control. Application rates and timing are generally the recommendations from herbicide labels.

Price elasticities of demand estimates characteristically vary widely in the published research. The elasticities chosen represent either midpoints among wide ranging alternatives or, in many instances, single estimates. Alternative price elasticity estimates affect the percentage price change for the crop when combined with estimated yield impacts and how that change is distributed between consumers and producers. Establishing confidence limits around the economic estimates is not possible given the methods used and the assumptions employed.

The information provided in the tables included in this chapter report the 1989 to 1991 average total planted acres in a particular commodity, average production for 1989 to 1991 as well as average price, both the number and percent of acres treated annually with either 2,4-D or another phenoxy herbicide, estimated annual use of 2,4-D or another phenoxy herbicide in pounds of acid equivalent, and rate of use per acre per crop year (rate times number of applications per year). Other information provided includes both estimated absolute changes in production and changes as a proportion of total production, estimated cost change per treated acre considering the cost of alternative weed control methods, and total cost change which is the product of per acre cost change and number of acres treated. Also provided are estimated price changes, net revenue changes to producers, the effect of quantity and price changes on consumers, and the subsequent net effect, plus the price elasticity of demand estimates where available, which were used to estimate the price change.

Aggregate data describing regional characteristics of phenoxy herbicide use in field crops and estimated yield and cost change impacts used by AGSIM as simulation input are discussed in the text as well as provided in Appendix Tables 1 through 5 of this chapter. What follows provides a synopsis of the major findings of the phenoxy herbicide assessment for each use classification. More in-depth analyses and a description of specific use impacts can be found in succeeding Chapters 5 through 13.

ALFALFA FORAGE, PASTURELAND, AND RANGELAND

One of the noteworthy findings of this report is the large amount of 2,4-D used on pastureland and rangeland in the United States (Table 1). These two uses account for about 15 million pounds of 2,4-D or about 27% of total phenoxy herbicide use reported in this assessment. An estimated 9.3 million pounds of 2,4-D is used annually by farmers to treat about 8.7 million acres of pastureland or about 8.3% of total acres in pastureland in the United States. The annual rate of applreported in this assessment. An estimated 9.3 million pounds of 2,4-D is used annually by farmers to treat about 8.7 million acres of pastureland or about 8.3% of total acres in pastureland in the United States. The annual rate of application is estimated at 1.1 lb/A. An additional 249,000 pounds of MCPA is used on pastureland at 1 lb/A. Another 5.9 million pounds of 2,4-D is used on 4.9 m

Alternative chemical controls that would be used on rangeland, pastureland, and alfalfa forage if 2,4-D were lost include dicamba, MCPA, picloram, triclopyr, glyphosate, bromoxynil, EPTC, and paraquat. Total herbicide use would decrease fdicamba, MCPA, picloram, triclopyr, glyphosate, bromoxynil, EPTC, and paraquat. Total herbicide use would decrease from 17 million pounds to 4.9 million pounds reflecting the large number of farmers and ranchers that would not treat for weed control if the cost of control increased significantly above the cost of current control methods. The total loss of phenoxy herbicides would cause farmers to substitute 4.6 million pounds of bromoxynil, EPTC, dicamba, paraquat, picloram, triclopyr, and glyphosate. Per acre weed (Table 2). Costs of weed management in alfalfa forage are projected to decrease by about $9.52/A because of the acreage left untreated.

The net societal impacts are measured as the cost of alternative control measures and the value of forage lost (Table 3). In alfalfa, though only about 8% of the acres are treated with phenoxy herbicides, the total acreage planted is sufficiently large and the estimated loss (5.2%) great enough to cause net grower revenue to decline by $234 million, and the price of alfalfa forage to increase by $81 million, resulting in a net societal loss of $315 million. A revenue loss of $54.2 million is projected for farmers maintaining pastureland acres with alternative weed control methods and materials while rangeland owners would incur an increase in weed management costs of $16.1 million. The value of the forage lost without phenoxy herbicides is estimated as $331 million in pastureland and $64 million in rangeland. The net revenue loss is therefore estimated as $385 million in pastureland and $80.4 million for rangeland owners. Because the quality of weed control would diminish with alternative management methods and with it forage quality and quantity, estimates based on previous published research indicate that farmers and ranchers would experience a combined loss of $780 million including the cost of alternative herbicides.

MAJOR FIELD CROPS

Major field crops for the purposes of this assessment are comprised of corn, soybean, sorghum, and peanut.

Approximately 5.6 million pounds of phenoxy herbicides are applied to 13.9 million acres of major field crops annually (Table 4). The herbicide 2,4-D comprises about 4.7 million pounds or 84% of the total, while 2,4-DB represents 930,000 pounds or 16%. The greatest use occurs in the production of corn where 3.3 million pounds of 2,4-D are applied annually, and soybean with 970,000 pounds of 2,4-D and 365,000 pounds of 2,4-DB. About 567,000 pounds of 2,4-DB are applied to peanut annually while sorghum receives about 484,000 pounds of 2,4-D. About 9.5% of major field crop acreage is treated annually with phenoxy herbicides at an average rate of 0.41 lb/A.

Popular herbicide alternatives to 2,4-D in field crops would include atrazine, bentazon, bromoxynil, dicamba, glyphosate, and paraquat. Use would increase from about 4.7 million pounds of 2,4-D currently being used to about 5.4 million pounds of alternative herbicides. If all phenoxy herbicides were lost farmers would use the alternative herbicides listed above, though in different proportions, but total use of alternatives was projected to remain about 5.4 million pounds.

The largest yield impacts should all phenoxy herbicides be lost would occur in peanut, sorghum, and soybean with estimated losses of 13.3%, 2.4%, and 1.2%, respectively (Table 5). In corn, yield losses would be much less. A loss of 0.9% in corn, however, translates into an estimated price increase of 1.9% (Table 6), and a net societal loss of $246 million. Other major net societal losses if all phenoxy herbicides are banned occur in soybean ($155 million) and peanut ($139 million). The net societal effect of banning 2,4-D in major field crop production is estimated as a loss of $311 million. Should all phenoxy herbicide uses be canceled in major field crop production the net societal loss would increase to $570 million.

The regional economic impact of losing the phenoxy herbicides in field crop production would not be distributed evenly. Tables 7 through 10 provide data that describe this uneven impact for each field crop included in this section. (Other field crop and small grain crop regional impacts are provided in Appendix Tables 4-1 through 4-5. In attempting to discern patterns in these distributional impacts, it is striking that, for crops grown in all regions, the largest yield impacts occur in the minor production regions. For instance, in corn, the greatest yield losses would occur in the Pacific, Southeast, Delta, and Mountain States, while in the Corn Belt and Lake States and Northern Plains, which together comprise 84% of corn acres, the yield impacts are relatively small (Table 7). In sorghum, where overall estimated yield loss is significant, the greatest declines are projected to occur in the Appalachian, Mountain, and Southeastern States (Table 9). Estimated yield impacts in the Northern Plains, where 55% of sorghum acreage is located, would approach 0.5%, considerably lower than the 10 to 13% yield losses projected for the aforementioned regions.

TURFGRASS

Turfgrass specialists surveyed estimated that there exists 23 million acres of turfgrass in the United States of which 18% is treated with 2,4-D. The principle broadleaf weeds in turfgrass are dandelion, buckhorn plantain, and broadleaf plantain which are controlled by 2,4-D but not with many other herbicides. Other phenoxy herbicides including MCPA, mecoprop, and dichlorprop are often used in combination with 2,4-D and non-phenoxy herbicides to reduce rates and increase the spectrum of broadleaf weed control.

Survey respondents estimated that 2.8 million pounds of 2,4-D are used annually that is valued at approximately $28 million. The annual cost of application of 2,4-D in turfgrass is $104 million. Current use of all phenoxy herbicides on turfgrass is approximately 5.2 million pounds valued at $64 million. Application costs are estimated to be $190 million. If 2,4-D were banned, there would be an increase in total herbicide cost and application of $95.7 million and $13.7 million, respectively. The greatest impacts would be a decrease in broadleaf weed control, and a shift of turfgrass service business activities away from pesticide application. If all phenoxy herbicides were banned from use in turfgrass there would be a $3.1 million increase in application costs of alternative herbicides and an increase of 64% or $107 million in herbicide costs. Because herbicides would not be available on some turfgrass there would be an estimated increase of $263 million annually to culturally improve turfgrass by over-seeding, applying additional fertilizer (in particular nitrogen), and renovation. The dollar loss to society of banning 2,4-D in turfgrass management is the difference in cost of alternative herbicides and application methods minus the current costs of 2,4-D use which is estimated as $232 million. The net societal loss resulting from a ban of all phenoxy herbicides in turfgrass, which includes the costs of alternative herbicides and application expenses as well as the costs of cultural improvement, amounts to $367 million.

The banning of 2,4-D and other phenoxy herbicides and use of alternatives for weed control would lead to a decline in the aesthetic quality and playability of sports fields and golf courses and increase the potential of water contamination by nitrogen. The herbicide 2,4-D and other phenoxy herbicides have been proven cost effective, efficient, and safe to use for weed management on turfgrass. This desirable combination of herbicide characteristics would be lost if use of alternative herbicides were required.

SMALL GRAINS

An estimated 10.7 million pounds of phenoxy herbicides are applied to small grains (wheat, oat, barley, and rye) annually (Table 11). The herbicide 2,4-D comprises about 7.8 million pounds of total use (74%) while MCPA use is estimated at 2.8 million pounds (26%). The greatest use occurs in wheat where 5.7 million pounds of 2,4-D and 1.4 million pounds of MCPA are applied. Significant use is also found in barley (1.6 million pounds of 2,4-D and 854,000 pounds of MCPA), and oat (400,000 pounds of 2,4-D and 595,000 of MCPA). About 35% of total small grain acres are treated annually with phenoxy herbicides at an average rate of 0.39 lb/A.

The largest crop yield impacts would occur as a result of a loss of all phenoxy herbicides (Table 12). Losses in the production of wheat could be as high as 2.2% of annual yield. Production of barley could drop by 3.8%, oat by 1.6%, and rye by 1.2%. Per acre increases in costs of production could total $4.18 for wheat, $3.94 for rye, $3.62 for barley, and $2.92 for oat should all phenoxy herbicides be lost. Popular herbicide alternatives to the phenoxy materials would include bromoxynil, dicamba, and tribenuron. If all phenoxy herbicides were lost, use of alternative herbicides would decrease to about 1.5 million pounds.

Yield losses combined with price elasticity of demand estimates provide estimated commodity price changes. The price of wheat could increase by 1.1% causing a $72.6 million loss in consumer surplus (Table 13). Combined with a loss in net revenue of $149 million from lower yields results in a net societal loss of $221 million in wheat production should all phenoxy herbicides be cancelled. The loss would be $113 million if only 2,4-D was cancelled. A projected increase of 2.3% in the price of barley would cause a loss of $20.4 million in consumer surplus and $28 million loss in net revenue resulting in a $48.4 million net loss if all phenoxy herbicides were banned, and $30.4 million if only 2,4-D were lost. The overall net societal effect of a 2,4-D cancellation in small grain production is projected as a loss of $148 million which increases to $284 million if all phenoxy herbicides are cancelled.

FALLOW LAND

The use of 2,4-D for weed control in fallowed farmland is significant. The phenoxy herbicide assessment survey results estimate about 7.2 million pounds of 2,4-D being used on 14.6 million acres of land in fallow in the United States in any particular year (Table 14). This represents phenoxy herbicide treatment on about 20% of land in fallow in the United States.

If 2,4-D was not available most acres would receive treatments of glyphosate (69%), dicamba (21%), and paraquat (6%). About 5.7 million pounds of herbicide alternatives would be used to replace the 7.2 million pounds of 2,4-D currently in use. Cost for weed control would increase by $132 million or about $9.08 per treated acre (Table 15). The net societal effect of losing 2,4-D is simply the cost change in using these alternative products as no specific commodity was associated with fallow acres. The net societal effect is, therefore, a loss of $132 million (Table 16).

NOXIOUS WEEDS

The control of noxious weed species is mandated by state and federal weed control laws. A number of Midwestern States report heavy use of phenoxy herbicides, primarily 2,4-D, in efforts to control noxious weeds. An estimated 2.2 million acres are treated annually in Nebraska, 2.1 million acres in South Dakota, and 1 million acres in Kansas. Significantly smaller acreages are treated annually in other regions of the United States; for example, 47,000 acres in Missouri, 50,000 acres in Idaho, and 29,000 acres in Minnesota. Thirty-five states have noxious weed control programs. An estimated 7 million acres are treated for noxious weeds in those 35 states, 75% with 2,4-D or other phenoxy herbicides at an annual cost of $135 million. Total phenoxy herbicide use for noxious weed control is estimated to be 5.25 million pounds. The loss of 2,4-D for noxious weed control would cause the cost of control to increase at least three-fold or $162 million above the current cost of 2,4-D and to $180 million above the current cost if all phenoxy herbicides are banned.

ORCHARD, VINEYARD, SOFT FRUIT, AND NUT

The producers of fruit and nut crops are not heavy users of phenoxy herbicides with about 379,000 pounds applied annually to about 351,000 acres of crops included in the survey at an average rate of 1.1 lb/A (Table 17). However, some crops receive relatively extensive treatment. About 26% of apple orchard acres (154,000 acres) receive about 188,000 pounds of 2,4-D at a rate of 1.2 lb/A. About 13% of peach orchard acres (30,000 acres) are treated with about 28,500 pounds of 2,4-D; 16% of almond acres (62,000 acres) are treated with 62,000 pounds of 2,4-D; and 21% of pear acres (17,000 acres) receive 19,000 pounds. Acres treated is also relatively significant for strawberry (16%), cherry (11%), and cranberry (10%). The principal alternative herbicides of choice for fruit and nut growers would be glyphosate and paraquat, and estimated quantities of active ingredients used would increase to 410,000 poundsrelatively extensive treatment. About 26% of appl

The estimated production impacts of a 2,4-D loss are generally inconsequential for most of the surveyed commodities (Table 18). The greatest yield losses would be experienced in apple production (1.4%) and strawberry (1.1%) while increased per acre costs of weed control would be greatest in nectarine ($38/A), pistachio ($34/A), walnut ($33/A), and apple ($26/A).

The producer and consumer surplus impacts are concentrated in apple production where an aggregate net societal loss of $84 million is projected in the combined fresh and processed markets (Table 19). Losses to consumers of strawberry fruit could total $22 million as a result of price increases though producer revenues would increase by an estimated $12.6 million resulting in a net societal loss of $9.4 million. Producers of blueberry, cherry, cranberry, processed grape, peach, pear, and plum would experience price increases proportionally greater than yield loss and subsequently experience a financial benefit. Overall, however, the loss of 2,4-D in the production of these commodities could result in a net societal loss of $111 million.

MISCELLANEOUS FIELD CROPS

Included in this group are dry pea, flax, green pea, millet, rice, seed crops, sugarcane, and wildrice. Approximately 1.8 million pounds of phenoxy herbicides are used annually in producing these commodities, with about half of the total applied to sugarcane (Table 20). About 41% of 855,000 sugarcane acres (347,000 acres) are treated with 923,000 pounds of 2,4-D at a rate of 2.7 lb/A per year. About 107,000 flax acres (39% of total flax acres) are treated with about 27,000 pounds of MCPA at a rate of 0.25 lb/A, while millet receives 28,000 pounds of 2,4-D on 52,000 acres (18% of total millet acres) at 0.54 lb/A. Other significant phenoxy herbicide use includes 79,000 pounds of MCPA applied to 102,000 acres of green pea (31% of the total crop), and 328,000 acres of seed crops treated with an estimated 231,000 pounds of phenoxy herbicides, principally 2,4-D (19% of total acres treated).

The loss of 2,4-D would cause growers to use atrazine, bentazon, bromoxynil, dicamba, glyphosate, MCPA, triclopyr, and propanil as herbicide alternatives. Alternative chemical use would total about 1.6 million pounds as compared with the current use of 1.67 million pounds of 2,4-D. Loss of all phenoxy herbicides would cause growers to use the same herbicides listed above excluding MCPA with 1.3 million pounds used as compared with the current 1.85 million pounds of all phenoxy herbicides.

Significant yield losses would occur in flax (6.7%), green pea (5.6%), and dry pea (2.5%) from the loss of MCPA and in sugarcane (5.7%) from the loss of 2,4-D (Table 21). In addition, impacts on production are significant for wildrice with a projected 4.5% yield decline while seed crops could expect a negative yield impact of 1%. The price of wildriceprojected 4.5% yield decline while seed crops could expect a negative yield impact of 1%. The price of wildrice could climb 14% in reaction to the decreased yield. Projected pri(Table 22). The estimated net societal effect resulting from the loss of phenoxy herbicides in sugarcane production is therefore a loss of $51 million resulting from yield loss and cost changes; in seed crops the loss would be $5.7 million. The net wildrice impact is a loss of $1 million. The net societal effect of the loss of phenoxy herbicides in this group of crops is a loss of $75 million, 68% of which is embodied in the cost increases for weed control combined with the dollar value yield loss in sugarcane. The net societal effect can be considered an underestimation of the true impacts in this group given the assumption regarding price stability.

RIGHTS-OF-WAY

There are over 3 million miles of paved and unpaved roadways, 170,000 miles of operating railroads, 6.1 million miles of electrical lines (87% distribution and 13% transmission), and 1.3 million miles of pipelines in the continental United States. An estimated 3.9 million acres of land are treated for weed control along these rights-of-way. Rights-of-way uses of phenoxy herbicides are generally for selective postemergence control of perennial broadleaf weeds and woody plants where they interfere with visibility, clog ditches, interfere with conductors, or pose an environmental problem. Phenoxy herbicides constitute a small percentage of dollar investment in rights-of-way vegetation management, but rank high in rate used and acres treated. Interval between applications generally ranges between 3 to 8 years depending on climate and proportion of woody species. Applications may be more frequent in the South or where there exist extensive noxious weed infestations. About 1.26 million pounds of 2,4-D and 22,000 pounds of dichlorprop are used yearly in maintenance of rights-of-way at an average annual application rate of 1 to 2 lb/A. Alternative chemical controls capable of controlling broadleaf weeds include triclopyr, dicamba, and picloram. The net societal impact of losing the phenoxy herbicides in rights-of-way weed management was estimated as $19.1 million, the added cost for using alternatives to 2,4-D, and $300,000, the added cost for using alternatives to dichlorprop. Hence the net societal effect of banning all phenoxy herbicides in rights-of-way uses is estimated as an annual loss of $19.4 million.

FORESTRY

Although phenoxy herbicides are used in all major areas of intensive forest production in the United States, their aggregate use is modest. Most of the use of 2,4-D occurs in the forests of the Pacific Northwest. Forest applications of 2,4-D are usually made aerially at a rate of about 1 to 2 lb/A, although labels permit up to 4 lb/A in site preparation. Use is estimated at about 220,000 pounds of phenoxy herbicides annually to about 116,000 acres at a rate of nearly 2 lb/A for conifer release.

Estimation of the annual cost to society, of losing either 2,4-D or all phenoxy herbicides, is complex in forestry. Calculations for annual crops are relatively easy, because costs of phenoxy herbicides, costs for alternatives, and effects on production can be estimated on a yearly basis. In contrast, an application of herbicide may be made only once in establishing a new forestry planting, but the effect of the treatment continues until the trees are harvested many years later. In forestry, the benefit of a production practice, such as the application of a herbicide, can be expressed as the increase in present net value (PNV) of the unit of land receiving the treatment. Calculations of the loss in PNV, if phenoxy herbicides were lost, are given in Chapter 11 of this report dealing with forestry. For the present purpose, which is estimating the annual cost of losing either 2,4-D or all phenoxy herbicides, only the increased cost of using alternative herbicides is considered. The annual increase in operating cost in forestry from substituting alternative herbicides for 2,4-D is estimated to be $17.2 million, and for substituting for diclorprop to be $605,000. Thus, the net societal effect from a ban of all phenoxy herbicides in forestry uses is estimated to be an annual loss of $17.8 million.

AQUATIC USES

Approximately 400,000 acres of inland water surface area are treated each year with herbicides for aquatic weed control. This represents 0.8% of the 50 million total acres of inland waters in the United States (Table 23). An estimated 56% of this treated water area (223,000 acres) receives an application of 2,4-D in either liquid or granular formulations amounting to about 702,000 pounds of 2,4-D applied at an average annual rate of 3.2 lb/A. The principal weeds targeted for control with 2,4-D are Eurasian watermilfoil on an estimated 10,000 acres and waterhyacinth on 213,000 acres.

The loss of 2,4-D for Eurasian watermilfoil control would cause users to substitute diquat, endothall, and fluridone on an estimated 40%, 40%, and 20%, respectively, of the acres currently treated with 2,4-D. Costs of control would increase from about $171/A currently expended for a 2,4-D treatment to a weighted average of $245/A for alternative herbicides (Tables 24, 25). Total cost of herbicides would increase from the $1.71 million expended on 2,4-D to $3.9 million for alternative herbicides. Total costs, therefore, for the 10,000 acres treated would increase by $2.2 million (Table 27).

The extent of waterhyacinth infestation is much greater than the infestation of Eurasian watermilfoil and would similarly result in significant cost increases for current users of 2,4-D if it were banned. The two principal alternatives are diquat and glyphosate which would be used on an estimated 70% and 30%, respectively, of the waterhyacinth infested acres currently treated with 2,4-D (Table 26). Costs of control would increase from about $5.12/A for the 2,4-D formulation currently in use to $74/A for the weighted average herbicide alternatives (Tables 24, 26). Total cost for herbicides would increase from current expenditures of about $1.1 million to $15.5 million, an increase of $14.4 million if 2,4-D were lost (Table 27).

The net societal loss of a regulatory ban of 2,4-D in aquatic uses is the summation of these cost impacts which are estimated to total about $16.6 million, or a weighted average increase of $74.65 per treated acre (Table 27).

VEGETABLES

Vegetables included in this assessment (asparagus and sweet corn) receive about 93,000 pounds of 2,4-D (Table 28). Although the absolute amount of herbicide applied is relatively minor, substantial acreage of the included commodities are treated with 2,4-D including 27% of asparagus acres and 14% of sweet corn. The heaviest use occurs on asparagus with 49,000 pounds applied annually to 26,000 acres at an average rate of 1.9 lb/A. About 119,000 acres of these two crops, or 15% of total acres, are treated annually with 2,4-D.

The loss of phenoxy herbicides would cause alternative herbicide use to shift to bentazon and glyphosate . About 60% of asparagus acres formerly treated with 2,4-D would receive a treatment of glyphosate. About 48% of sweet corn acres currently treated with 2,4-D would receive atrazine. About an equal amount of alternative herbicides would replace the 93,000 pounds of 2,4-D currently in use.

Though yield loss would be significant for asparagus (4.9%), net revenue of farmers would improve markedly due to large increases in commodity prices (Tables 29, 30). Estimates indicate that the loss of phenoxy herbicides would cause asparagus prices to increase by 23%, while sweet corn prices could rise by 2.4%. Aggregate benefit to farmers from these price increases would total $27 million under a 2,4-D loss scenario. The loss in buying power to consumers of these supply-induced price increases could total more than $39 million from the loss of 2,4-D. The net societal loss is estimated at $12 million with a ban of 2,4-D.

• Table of Contents Tables for Chapter 4

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TABLES FOR CHAPTER 4

Table 1. Phenoxy herbicide use in alfalfa forage, pastureland, and rangeland in the United States.

Crop	Acres in production in 1987	Average annual production	Yield units	Average price per unit	Acres treated with phenoxy herbicides[a]		Pounds phenoxy herbicides used[a]	Annual use rate
	(000)	(000)		($)	(000)	(%)	(000)	(lb/A)
Alfalfa forage	25,659	81,573	ton	77.82	1,985[b]	7.7	1,517[b]	0.76
Pastureland	105,532	NE[c]	NA[d]	NE	8,731	8.3	9,330	1.1
					249[e]	0.2	249[e]	1.0
Rangeland	410,328	NE	NA	NE	4,899	1.2	5,867	1.2
Total	541,519				15,864	2.9	16,963	1.1

[a] Based on 1993 survey of 1992 data and repesents 2,4-D unless otherwise noted.
[b] 2,4-DB.
[c] NE = not estimated.
[d] NA = not applicable.
[e] MCPA.

Table 2. Estimated changes in production and in cost of production in alfalfa forage, pastureland, and rangeland with the loss of phenoxy herbicides in the United States during 1992.

Crop	Production change		Yield unit	Cost change per acre previously treated with phenoxy herbicides	Total cost change
	Quantity	Proportion of total			
	(000)	($)	(%)		$(000)
Alfalfa forage	-4,242	-5.2	ton	-9.52	-18,900
Pastureland	NE[a]	NE	NA[b]	6.12	54,200
Rangeland	NE	NE	NA	3.29	16,100

[a] NE = not estimated.

[b] NA = not applicable.

Table 3. Estimated economic effects of a ban of either 2,4-D or all phenoxy herbicides in alfalfa forage, pastureland, and rangeland in the United States during 1992.

Crop	Price change	Price elasticity of demand	Net revenue change[a]	Consumer effect	Net societal effect
	(%)		$(000)	$(000)	$(000)
Alfalfa forage	1.3	-0.51	-234,000[b]	-81,000[b]	-315,000[b]
Pastureland	NE[c]	NE	-384,200	NE	-384,200[d]
Rangeland	NE	NE	-80,400	NE	-80,400[e]
Total			**-698,600**	**-81,000**	**-779,600**

[a] Reflects loss of only 2,4-D unless otherwise noted.

[b] Reflects loss of all phenoxy herbicides.

[c] NE = Not estimated.

[d] Includes increased costs of weed control and estimated value of lost yield if all phenoxy herbicides were banned. If only 2,4-D were banned, the loss is estimated as $383.4 million.

[e] Includes decreased costs of weed control and estimated value of lost yield if all phenoxy herbicides were banned. If only 2,4-D were banned, the loss is estimated as $79.5 million.

Table 4. Yearly production, price, and phenoxy herbicide use in major field crops in the United States.

Crop	Average acres in production 1989-91	Average annual production 1989-91	Yield units	Average price per unit	Acres treated with phenoxy herbicides[a]		Pounds phenoxy herbicides used	Annual use rate
	(000)	(000)		($)	(000)	(%)	(000)	(lb/A)
Corn	73,823	9,764,000	bu	2.02	7,900	10.7	3,307	0.42
Soybean	59,200	1,945,059	bu	5.71	1,771	3.0	917	0.52
					1,407[b]	2.4	365[b]	0.26
Sorghum	11,399	589,404	bu	1.70	1,270	11.1	484	0.38
Peanut	1,848	4,173,112	lb	0.26	1,530[b]	82.8	567[b]	0.37
Total	**146,270**				13,878	9.5	5,640[c]	0.41

[a] Based on 1993 survey of 1992 data and represents 2,4-D unless otherwise noted.
[b] 2,4-DB.
[c] 2,4-D = 4,708,000 lb.
2,4-DB = 932,000 lb.

Table 5. Estimated changes in production and in cost of production with the loss of phenoxy herbicides for major field crops in the United States during 1992.

Crop	Production change[a]		Yield unit	Cost change per acre previously treated with phenoxy herbicides	Total cost change
	Quantity	Proportion of total			
	(000)	(%)		($)	$(000)
Corn	-92,000	-0.94	bu	6.55	51,738
Soybean	-4,085	-0.21	bu	6.34	11,224
	-23,341[b]	-1.2			20,204
Sorghum	-14,146	-2.4	bu	4.98	6,300
Peanut[c]	-504,947	-13.3	lb	2.86	4,300

[a] Production change indicates loss of only 2,4-D unless otherwise noted.
[b] Loss of all phenoxy herbicides.
[c] 2,4-DB is the only phenoxy herbicide used on peanut.

Table 6. Estimated economic effects of a ban of 2,4-D or all phenoxy herbicides in major field crops in the United States during 1992.

Crop	Price change (%)	Price elasticity of demand	Net revenue change[a] $(000)	Consumer effect $(000)	Net societal effect $(000)
Corn	1.9	-0.21	-51,739	-194,362	-246,101
Soybean	1.6	-0.77	-4,318	-30,274	-34,591
			17,549[b]	-172,137[b]	-154,588[b]
Sorghum	0.7	-0.34	-24,200	-6,500	-30,700
Peanut	1.5	-0.09	-123,000[b]	-15,900[b]	-138,900[b]
Total with only 2,4-D banned			-80,257	-231,136	-311,392
Total with all phenoxy herbicides banned			-181,390	-388,899	-570,289

[a] Reflects loss of only 2,4-D unless otherwise noted.
[b] Reflects loss of all phenoxy herbicides.

Table 7. Cost and yield changes in corn production by region and for the United States during 1992 if phenoxy herbicides were lost.

Regions in the United States[a]	Distribution of corn acres by region (%)	Acres treated with phenoxy herbicides (%)	Average yield loss without phenoxy herbicides (%)	Average weed control cost increase without phenoxy herbicides ($/A)
Corn Belt	47.7	11.1	0.9	6.60
Lake States	17.3	8.7	0.2	6.01
Northern Plains	18.8	9.2	0.6	7.05
Southern Plains	2.4	5.9	0.0	1.86
Delta	0.6	34.1	6.4	9.38
Mountain	1.7	25.2	4.5	3.96
Pacific	0.7	13.3	9.3	5.12
Northeast	4.8	10.2	0.9	6.79
Appalachian	4.2	10.4	0.9	9.05
Southeast	1.3	17.2	8.2	5.47
Alabama	0.4	40.0	5.0	7.40
United States	99.5[b]	10.7	0.94	6.55

[a] Corn Belt: IA, IL, IN, OH, MO
Lake States: MN, MI, WI
Northern Plains: ND, SD, NE, KS
Southern Plains: OK, TX
Delta: MS, LA, AR
Mountain: MT, ID, WY, CO, NM
Pacific: CA, WA, OR
Northeast: PA, NY, MD, DE, NJ, MA, CT, NH, ME
Appalachian: WV, VA, NC, KY
Southeast: GA, SC, FL
[b] Does not sum to 100% due to rounding error.

Table 8. Cost and yield changes in soybean production by region and for the United States during 1992 if phenoxy herbicides were lost.

Regions in the United States[a]	Distribution of soybean acres by region (%)	Acres treated with phenoxy herbicides (%)	Average yield loss without phenoxy herbicides (%)	Average weed control cost increase without phenoxy herbicides ($/A)
Corn Belt	50.7	11.2	1.5	6.04
Lake States	11.5	3.2	0.0	2.84
Northern Plains	12.0	5.4	0.4	5.78
Southern Plains	1.0	0.0	0.0	0.0
Delta	11.8	1.5	0.0	12.46
Mountain	0.0	0.0	0.0	0.0
Pacific	0.0	0.0	0.0	0.0
Northeast	2.0	7.9	6.3	12.51
Appalachian	7.5	3.2	3.0	28.49
Southeast	2.9	0.0	0.0	0.0
Alabama	0.8	0.0	0.0	0.0
United States	99.4[b]	7.2	1.2	7.94

[a] Corn Belt: IA, IL, IN, OH, MO
Lake States: MN, MI, WI
Northern Plains: ND, SD, NE, KS
Southern Plains: OK, TX
Delta: MS, LA, AR
Mountain: MT, ID, WY, CO, NM
Pacific: CA, WA, OR
Northeast: PA, NY, MD, DE, NJ, MA, CT, NH, ME
Appalachian: WV, VA, NC, KY
Southeast: GA, SC, FL

[b] Does not sum to 100% due to rounding error.

Table 9. Cost and yield changes in sorghum production by region and for the United States during 1992 if phenoxy herbicides were lost.

Regions in the United States[a]	**Distribution of sorghum acres by region (%)**	**Acres treated with phenoxy herbicides (%)**	Average yield loss without phenoxy herbicides (%)	Average weed control cost increase without phenoxy herbicides ($/A)
Corn Belt	4.6	12.0	2.0	4.18
Lake States	0.0	0.0	0.0	0.0
Northern Plains	54.7	18.9	0.5	4.48
Southern Plains	9.7	17.0	0.0	5.77
Delta	14.5	15.2	2.7	7.91
Mountain	8.5	14.0	10.0	1.94
Pacific	0.0	0.0	0.0	0.0
Northeast	0.0	0.0	0.0	0.0
Appalachian	3.9	15.5	10.3	6.12
Southeast	3.1	32.6	12.8	2.80
Alabama	1.0	15.0	0.0	6.17
United States	100.	17.7	2.4	4.91

[a] Corn Belt: IA, IL, IN, OH, MO
Lake States: MN, MI, WI
Northern Plains: ND, SD, NE, KS
Southern Plains: OK, TX
Delta: MS, LA, AR
Mountain: MT, ID, WY, CO, NM
Pacific: CA, WA, OR
Northeast: PA, NY, MD, DE, NJ, MA, CT, NH, ME
Appalachian: WV, VA, NC, KY
Southeast: GA, SC, FL

Table 10. Cost and yield changes in peanut production by region and for the United States during 1992 if phenoxy herbicides were lost.

Regions in the United States[a]	Distribution of peanut acres by region (%)	Acres treated with phenoxy herbicides (%)	Average yield loss without phenoxy herbicides (%)	Average weed control cost increase without phenoxy herbicides ($/A)
Corn Belt	0.0	0.0	0.0	0.0
Lake States	0.0	0.0	0.0	0.0
Northern Plains	0.0	0.0	0.0	0.0
Southern Plains	22.2	42.5	1.5	8.75
Delta	0.0	0.0	0.0	0.0
Mountain	0.0	0.0	0.0	0.0
Pacific	0.0	0.0	0.0	0.0
Northeast	0.0	0.0	0.0	0.0
Appalachian	14.1	74.0	6.9	1.03
Southeast	49.4	98.8	20.0	1.29
Alabama	14.3	80.0	15.0	0.65
United States	100.	80.2	13.3	2.82

[a] Corn Belt: IA, IL, IN, OH, MO
Lake States: MN, MI, WI
Northern Plains: ND, SD, NE, KS
Southern Plains: OK, TX
Delta: MS, LA, AR
Mountain: MT, ID, WY, CO, NM
Pacific: CA, WA, OR
Northeast: PA, NY, MD, DE, NJ, MA, CT, NH, ME
Appalachian: WV, VA, NC, KY
Southeast: GA, SC, FL

Table 11. Yearly production, price, and phenoxy herbicide use in small grain crops in the United States.

Crop	Average acres in production 1989-91 (000)	Average annual production 1989-91 (000)	Yield units	Average price per unit ($)	Acres treated with phenoxy herbicides[a] (000)	Acres treated with phenoxy herbicides[a] (%)	Pounds phenoxy herbicides used (000)	Annual use rate (lb/A)
Wheat	57,912	2,251,250	bu	2.92	14,700	25.5	5,700	0.39
					3,900[b]	6.8	1,379[b]	0.38
Oat	10,386	324,546	bu	0.77	1,100	10.6	400	0.36
					1,500[b]	14.4	595[b]	0.40
Barley	8,757	430,298	bu	1.92	3,700	42.3	1,600	0.43
					2,137[b]	24.4	854[b]	0.40
Rye	1,770	11,195	bu	1.56	218	12.3	124	0.57
Total	**78,825**				27,255	34.6	10,652[c]	0.39

[a] Based on 1993 survey of 1992 data and represent 2,4-D unless otherwise noted.
[b] MCPA.
[c] 2,4-D = 7,824.
MCPA = 2,828.

Table 12. Estimated changes in production and in cost of production of small grain crops with the loss of phenoxy

herbicides in the United States during 1992.

Crop	Production change[a]		Yield unit	Cost change per acre previously treated with phenoxy herbicides	Total cost change
	Quantity (000)	Proportion of total (%)		($)	$(000)
Wheat	-19,136	-0.85	bu	4.18	56,511
	-49,528[b]	-2.2			72,800
Oat	-1,298	-0.4	bu	2.92	3,716
	-3,895[b]	-1.6			6,700
Barley	-9,036	-2.1	bu	3.62	12,884
	-12,909[b]	-3.8			21,500
Rye	-91	-0.81	bu	1.52	329
	-137[b]	-1.2		3.94	821

[a] Production change indicates loss of only 2,4-D unless otherwise noted.
[b] Loss of all phenoxy herbicides.

Table 13. Estimated economic effects of a ban of either 2,4-D or all phenoxy herbicides in small grain crops in the United States during 1992.

Crop	Price change (%)	Price elasticity of demand	Net revenue change[a] $(000)	Consumer effect $(000)	Net societal effect $(000)
Wheat	1.1	-0.015	-40,997	-71,734	-112,731
			-148,600[b]	-72,600[b]	-221,000[b]
Oat	0.4	-0.97	-3,755	-984	-4,726
	1.7[b]		-12,600[b]	-979[b]	-13,600[b]
Barley	2.3	-0.019	-11,303	-19,160	-30,463
			-28,000[b]	-20,400[b]	-48,400[b]
Rye	0.0	perfectly elastic[c]	-473	0	-473
			-965[b]		-965[b]
Total with only 2,4-D banned			**-56,528**	-91,878	-148,393
Total with all phenoxy herbicides banned			-190,165	-93,979	-283,965

[a] Revenue change, consumer effects, and net effects reflect loss of only 2,4-D unless otherwise noted.
[b] Reflects loss of all phenoxy herbicides.
[c] Assumed perfectly elastic demand to allow revenue and surplus estimation.

Table 14. Phenoxy herbicide use on fallow land in the United States.

Crop	Acres in production 1987 (000)	Average annual production (000)	Yield units	Average price per unit ($)	Acres treated with phenoxy herbicides[a]		Pounds phenoxy herbicides used[a] (000)	Annual use rate (lb/A)
					(000)	(%)		
Fallow	72,000	NA[b]	NA	NA	14,598	20.3	7,210	0.5

[a] Based on 1993 survey of 1992 data and represents 2,4-D unless otherwise noted.
[b] NA = not applicable.

Table 15. Estimated changes in production and in cost of production in fallow land with the loss of phenoxy herbicides in the United States during 1992.

Crop	Production change		Yield unit	Cost change per acre previously treated with phenoxy herbicides	Total cost change
	Quantity (000)	Proportion of total (%)		($)	$(000)
Fallow	NE[a]	NE	NA[b]	9.08	132,400

[a] NE = not estimated.
[b] NA = not applicable.

Table 16. Estimated economic effects of a ban of 2,4-D or all phenoxy herbicides in fallow land in the United States during 1992.

Crop	Price change (%)	Price elasticity of demand	Net revenue change[a] $(000)	Consumer effect $(000)	Net societal effect $(000)
Fallow	NE[b]	NE	-132,400	NE	-132,400

[a] Reflects loss of only 2,4-D unless otherwise noted.
[b] NE = Not estimated.

Table 17. Yearly production, price, and phenoxy herbicide use on orchard, vineyard, soft fruit, and nut crops in the United States.

Crop	Acres in production 1987 (000)	Average annual production 1989-91 (000)	Yield units	Average price per unit ($)	Acres treated with phenoxy herbicides[a] (000)	Acres treated with phenoxy herbicides[a] (%)	Pounds phenoxy herbicides used (000)	Annual use rate (lb/A)
Almond	401[b]	547,000	lb	1.00	62.1	15.5	62.1	1.0
Apple	601	4,067,435[c] 3,088,371[d]	lb	0.87 0.18	154.	25.6	188.	1.2
Apricot	24	112.5	ton	651.83	1.4	5.9	1.5	1.1
Avocado	87[b]	130.3	ton	1,597.	0.8	0.9	2.4	3.0
Blueberry	37	26,267	lb	1.23	0.6	1.5	0.56	0.93
Cherry	131	95.7	ton	784.83	13.8	10.5	15.	1.1
Coffee	2.1	2,850	lb	2.99	.043	2.0	.128	3.0
Cranberry	27.5[b]	3,587	bbl	45.67	2.7	10.0	7.0	2.6
Grape	833	11,293,700[c] 4,834[d]	lb ton	1.36 450.61	27.0	3.2	16.7	0.62
Nectarine	33	226.2	ton	430.87	1.5	4.5	1.47	0.98
Peach	240	986,600	lb	0.25	30.0	12.7	28.5	0.95
Pear	84	896.3	ton	283.44	17.0	21.0	19.0	1.1
Pistachio	65[b]	78,667	lb	1.30	3.2	5.0	3.2	1.0
Plum and prune	151	241.8	ton	293.00	10.5	7.4	8.0	0.76
Strawberry	46[b]	12,244	cwt	69.67	7.2	15.6	9.9	1.4
Walnut	213	238.3	ton	1,063.	19.0	9.0	15.6	0.82
Total	2,976				**350.8**	11.8	**379.1**	**1.1**

[a] Based on 1993 survey of 1992 data and represent 2,4-D unless otherwise noted.
[b] 1989-1991 average acreage.
[c] Fresh market.
[d] Processed market.

Table 18. Estimated changes in production and in cost of production for orchard, vineyard, soft fruit, and nut crops

with the loss of phenoxy herbicides in the United States during 1992.

Crop	Production change[a]		Yield unit	Cost change per acre previously treated with phenoxy herbicides	Total cost change
	Quantity (000)	Proportion of total (%)		($)	$(000)
Almond	0	0	lb	17.16	1,065
Apples	-43,237	-1.4	lb	22.88	3,524
Apricots	-0.22	-0.2	ton	19.13	27.4
Avocado	0	0	ton	24.32	19.3
Blueberry	-40	-0.15	lb	-3.14	-0.2
Cherry	-0.5	-0.51	ton	10.58	146.0
Coffee	-8.7	-0.30	lb	15.80	<1.0
Cranberry	-24	-0.65	bbl	22.00	60.6
Grape	-4,266	-0.04	lb	24.89	764.2
Nectarine	-0.21	-0.09	ton	37.74	55.0
Peach	-4,900	-0.50	lb	4.94	150.1
Pear	-5	-0.57	ton	22.60	345.
Pistachio	0	0	lb	34.43	111.2
Plum and prune	-1.8	-0.73	ton	25.27	281.2
Strawberry	-129	-1.1	cwt	10.00	71.4
Walnut	0	0	ton	32.97	623.8

[a] Production change indicates loss of only 2,4-D unless otherwise noted.

Table 19. Estimated economic effects of a ban of either 2,4-D or all phenoxy herbicides in orchard, vineyard, soft fruit, and nut production in the United States during 1992.

Crop	Price change (%)	Price elasticity of demand	Net revenue change[a] $(000)	Consumer effect $(000)	Net societal effect $(000)
Almond	0	-0.1685	-1,065	0	-1,065
Apple	1.2[b]	-1.159	-3,500	-9,100	-12,600
	1.0[c]	-1.348	-20,400	-50,500	-70,900
Apricot	1.3	-0.1509	820	-1,000	-180
Avocado	0	-0.4159	-19	0	-19
Blueberry	1.0	-0.1509	1,000	-1,200.	-200
Cherry	1.2	-0.4159	1182	-2280.	-1098.
Coffee	0.0	-0.1761	-26.4	0.0	-26.4
Cranberry	1.6	-0.4159	1,500	-2,700.	-1,200
Grape	0.16[b]	-0.232	2,300	-3,800.	-1,500
Grape	0.03[c]	-1.1795	-1100	-5,300	-6,400
Nectarine	0.2	-0.4159	71	-216.	-145
Peach	1.2	-0.4159	4,100	-7,300.	-3,200
Pear	1.4	-0.4159	1,656	-3,449.	-1,793
Pistachio	0	-0.1685	-111	0	-111
Plum and prunes	1.8	-0.4159	480	-1,320.	-840
Strawberry	2.5	-0.4159	12,600	-22,000.	-9,400
Walnut	0	-0.1685	-624	0	-624
		Total with 2,4-D banned	**-1,136**	-110,165	-111,301

[a] Revenue change, consumer effects, and net effects reflect loss of only 2,4-D unless otherwise noted.
[b] Processed market.
[c] Fresh market.

Table 20. **Yearly production, price, and phenoxy herbicide use in miscellaneous field crops in the United States.**

Crop	Average acres in production 1989-91 (000)	Average annual production 1989-91 (000)	Yield units	Average price per unit ($)	Acres treated with phenoxy herbicides[a] (000)	Acres treated with phenoxy herbicides[a] (%)	Pounds phenoxy herbicides used (000)	Annual use rate (lb/A)
Dry pea	233	389,100	lb	0.07	57.1	24.4	12.9[b]	0.23
Flax	273	3,709	bu	4.52	107	39.2	26.7[b]	0.25
Green pea	330	474	ton	259.	102.3	31.0	79.0[b]	0.77
Millet	292[c]	4,419	cwt	7.00	52	17.8	28.0	0.54
Rice	2,859	171,600	cwt	6.47	530	18.5	530	1.00
					14[b]	0.5	14[b]	1.00
Seed crops	1,730[c]	475,513	lb	0.87	265	15.3	193	0.73
					34[b]	2.0	17.0[b]	0.50
					29[d]	1.7	21.0[d]	0.72
Sugarcane	855	29,405	ton	29.74	347	40.6	922.9	2.7
Wildrice	28	16,380	lb	1.68	1.9	6.8	.480	0.25
Total	6,600				1,539.3	23.3	1,845	1.2

[a] Based on 1993 survey of 1992 data and represent 2,4-D unless otherwise noted.

[b] MCPA and MCPA plus MCPB in green pea.

[c] 1987 Census of Agriculture.

[d] 2,4-DB.

Table 21. Estimated changes in production and cost of production in miscellaneous field crops with the loss of phenoxy herbicides in the United States during 1992.

Crop	Production change[a]		Yield unit	Cost change per acre previously treated with phenoxy herbicides	Total cost change
	Quantity (000)	Proportion of total (%)		($)	$(000)
Dry pea	-9,728	-2.5	lb	0.72	41.0
Flax	-250[b]	-6.7	bu	3.98	426.1
Green pea	-26.5	-5.6	ton	7.86	800
Millet	-79	-1.8	cwt	0.55	28.2
Rice	-800	-0.5	cwt	2.07	1,130
Seed crops	-3,854	-1.0	lb	7.14	2.2
Sugarcane	-1,662	-5.7	ton	4.81	1,685
Wildrice	-557	-4.5	lb	-0.80	-1.5

[a] Production change indicates loss of only 2,4-D unless otherwise noted.
[b] Loss of all phenoxy herbicides.

Table 22. Estimated economic effects of a ban of either 2,4-D or all phenoxy herbicides in miscellaneous field crops in the United States during 1992.

Crop	Price change (%)	Price elasticity of demand	Net revenue change[a] $(000)	Consumer effect $(000)	Net societal effect $(000)
Dry pea	19.7	-0.1248	3,300.[b]	-3,900.[b]	-600.[b]
Flax	6.9	-0.9795	-480[b]	-1,116[b]	-1,596[b]
Green pea	10.4	-0.5335	4,400.[b]	-12,400.[b]	-8,000.[b]
Millet	1.8	-0.9795	-27	-561	-588
Rice	1.5	-0.32	8,691	-15,405	-6,714
Seed crops	0.0	perfectly elastic[c]	-5,700.	0.0	-5,700.
Sugarcane	0.0	perfectly elastic[c]	-51,096	0.0	-51,096
Wildrice	14.0	-0.32	1,862.	-2,863.	-1,002.
Total with only 2,4-D banned			**-46,270**	-18,829	-65,100
Total with all phenoxy herbicides banned			-39,050	-36,245	-75,296

[a] Revenue change, consumer effects, and net effects reflect loss of only 2,4-D unless otherwise noted.

[b] Loss of all phenoxy herbicides.

[c] Assumed perfectly elastic demand curve to allow revenue and surplus estimations.

Table 28. Yearly production, price, and phenoxy herbicide use in selected vegetables in the United States.

Crop	Average acres in production 1989-91 (000)	Average annual production 1989-91 (000)	Yield units	Average price per unit ($)	Acres treated with phenoxy herbicides[a] (000)	Acres treated with phenoxy herbicides[a] (%)	Pounds phenoxy herbicides used (000)	Annual use rate (lb/A)
Asparagus	95	2,398	cwt	62.47	26.0	27.4	49.0	1.9
Sweet corn	136[b]	15,800	cwt	16.33	93.0	13.7	43.7	0.47
	543[c]	3,255	ton	69.27				
Total	774				119	15.4	**92.7**	

[a] Based on the 1993 survey of 1992 data and represent 2,4-D unless otherwise noted.
[b] Fresh market.
[c] Processed market.

Table 29. Estimated changes in production and in cost of production of selected vegetables with the loss of phenoxy

herbicides in the United States during 1992.

Crop	Production changea		Yield unit	Cost change per acre previously treated with phenoxy herbicides	Total cost change
	Quantity	Proportion of total (%)			
	(000)			($)	$(000)
Asparagus	-118	-4.9	cwt	8.77	230
Sweet corn	-37b	-0.37	cwt	18.45	1,716
	-11c	-0.37	ton		

a Production change indicates loss of only 2,4-D unless otherwise noted.

b Fresh.

c Processed.

Table 30. Estimated economic effects of a ban of either 2,4-D or all phenoxy herbicides in selected vegetables in the

United States during 1992.

Crop	Price change (%)	Price elasticity of demand	Net revenue changea $(000)	Consumer effect $(000)	Net societal effect $(000)
Asparagus	23.0	-0.2152	23,000	-31,000.	-8,000
Sweet corn	1.4b	-0.255	823	-2,600.	-1,777
	2.4c	-0.1509	3,381	-5,800.	-2,419
Total			**27,204**	-39,400	-12,196

a Revenue change, consumer effects, and net effects reflect loss of only 2,4-D unless otherwise noted.

b Fresh.

c Processed.

APPENDIX TABLES FOR CHAPTER 4

<u>Appendix Table 4-1.</u> Cost and yield changes in alfalfa forage production by region in the United States during 1992 if phenoxy herbicides were lost.

Regions in the United States[a]	Distribution of alfalfa forage acres by region (%)	Acres treated with phenoxy herbicides (%)	**Average yield loss without phenoxy herbicides (%)**	Average weed control cost change without phenoxys ($/A)
Corn Belt	16.6	8.1	1.6	-4.81
Lake States	24.9	3.8	7.7	-11.20
Northern Plains	24.3	1.1	2.0	-9.39
Southern Plains	2.2	7.0	16.1	-10.80
Delta	2.7	80.0	10.0	+8.11
Mountain	8.6	7.5	2.5	-8.24
Pacific	3.7	21.9	14.0	-16.87
Northeast	7.6	9.4	2.5	-10.28
Appalachian	2.8	6.5	5.1	-11.71
Southeast	3.5	14.1	14.1	-18.43
Alabama	3.1	20.0	10.0	-15.82
United States	100	8.3	5.2	-9.47

[a] Corn Belt: IA, IL, IN, OH, MO
Lake States: MN, MI, WI
Northern Plains: ND, SD, NE, KS
Southern Plains: OK, TX
Delta: MS, LA, AR
Mountain: MT, ID, WY, CO, NM
Pacific: CA, WA, OR
Northeast: PA, NY, MD, DE, NJ, MA, CT, NH, ME
Appalachian: WV, VA, NC, KY
Southeast: GA, SC, FL

<u>Appendix Table 4-2.</u> Cost and yield changes in barley production by region in the United States during 1992 if phenoxy herbicides were lost.

Regions in the United States[a]	Distribution of barley acres by region (%)	Acres treated with phenoxy herbicides (%)	**Average yield loss without phenoxy herbicides (%)**	Average weed control cost increase without phenoxys ($/A)
Corn Belt	0.0	0.0	0.0	0.0
Lake States	12.9	49.4	0.08	3.88
Northern Plains	43.3	41.7	4.4	3.90
Southern Plains	0.6	11.7	0.0	3.99
Delta	0.0	0.0	0.0	0.0
Mountain	26.9	52.3	6.5	2.07
Pacific	11.8	34.0	0.5	2.22
Northeast	2.7	20.6	1.9	11.17
Appalachian	1.8	20.0	1.4	2.94
Southeast	0.2	50.0	0.0	2.38
Alabama	0.0	0.0	0.0	0.0
United States	100.2[b]	43.5	3.8	3.39

[a] Corn Belt: IA, IL, IN, OH, MO
Lake States: MN, MI, WI
Northern Plains: ND, SD, NE, KS
Southern Plains: OK, TX
Delta: MS, LA, AR
Mountain: MT, ID, WY, CO, NM
Pacific: CA, WA, OR
Northeast: PA, NY, MD, DE, NJ, MA, CT, NH, ME
Appalachian: WV, VA, NC, KY
Southeast: GA, SC, FL
[b] Does not sum to 100% due to rounding error.

<u>Appendix Table 4-3.</u> Cost and yield changes in oat production by region in the United States during 1992 if phenoxy herbicides were lost.

Regions in the United States[a]	Distribution of oat acres by region (%)	Acres treated with phenoxy herbicides (%)	Average yield loss without phenoxy herbicides (%)	Average weed control cost increase without phenoxy herbicides ($/A)
Corn Belt	13.3	3.1	0.0	0.42
Lake States	33.8	9.2	0.23	2.39
Northern Plains	38.7	15.9	2.8	3.36
Southern Plains	0.0	0.0	0.0	0.0
Delta	0.1	10.0	10.0	0.0
Mountain	1.6	33.4	5.3	1.21
Pacific	1.3	10.0	0.0	0.23
Northeast	7.1	28.8	0.0	6.09
Appalachian	0.1	5.0	20.0	0.0
Southeast	2.4	32.8	11.1	2.75
Alabama	0.8	10.0	10.0	0.0
United States	99.7[b]	13.3	1.6	2.69

[a] Corn Belt: IA, IL, IN, OH, MO
Lake States: MN, MI, WI
Northern Plains: ND, SD, NE, KS
Southern Plains: OK, TX
Delta: MS, LA, AR
Mountain: MT, ID, WY, CO, NM
Pacific: CA, WA, OR
Northeast: PA, NY, MD, DE, NJ, MA, CT, NH, ME
Appalachian: WV, VA, NC, KY
Southeast: GA, SC, FL
[b] Does not sum to 100% due to rounding error.

<u>Appendix Table 4-4.</u> Cost and yield changes in rice production by region in the United States during 1992 if phenoxy herbicides were lost.

Regions in the United States[a]	Distribution of rice acres by region (%)	Acres treated with phenoxy herbicides (%)	Average yield loss without phenoxy herbicides (%)	Average weed control cost increase without phenoxy herbicides ($/A)
Corn Belt	0.0	0.0	0.0	0.0
Lake States	0.0	0.0	0.0	0.0
Northern Plains	0.0	0.0	0.0	0.0
Southern Plains	13.9	3.0	0.0	1.03
Delta	70.7	27.6	1.5	2.74
Mountain	0.0	0.0	0.0	0.0
Pacific	15.3	7.5	5.0	0.0
Northeast	0.0	0.0	0.0	0.0
Appalachian	0.0	0.0	0.0	0.0
Southeast	0.2	10.0	20.0	-3.22
Alabama	0.0	0.0	0.0	0.0
United States	100.1[b]	21.1	0.48	2.07

[a] Corn Belt: IA, IL, IN, OH, MO
Lake States: MN, MI, WI
Northern Plains: ND, SD, NE, KS
Southern Plains: OK, TX
Delta: MS, LA, AR
Mountain: MT, ID, WY, CO, NM
Pacific: CA, WA, OR
Northeast: PA, NY, MD, DE, NJ, MA, CT, NH, ME
Appalachian: WV, VA, NC, KY
Southeast: GA, SC, FL
[b] Does not sum to 100% due to rounding error.

<u>Appendix Table 4-5.</u> Cost and yield changes in wheat production by region in the United States during 1992 if phenoxy herbicides were lost.

Regions in the United States[a]	Distribution of wheat acres by region (%)	Acres treated with phenoxy herbicides (%)	Average yield loss without phenoxy herbicides (%)	Average weed control cost increase without phenoxy herbicides ($/A)
Cornbelt	11.3	6.4	1.8	3.26
Lake States	1.9	27.5	3.4	2.91
Northern Plains	36.4	27.6	1.7	2.78
Southern Plains	25.9	17.7	0.0	4.78
Delta	4.0	22.2	1.7	17.32
Mountain	6.7	38.7	7.6	2.43
Pacific	6.8	33.3	5.4	3.89
Northeast	1.2	20.0	1.6	11.73
Appalachian	3.9	21.8	7.6	2.63
Southeast	1.9	54.9	3.1	3.01
Alabama	0.0	0.0	0.0	0.0
United States	100	23.8	2.2	4.10

[a] Corn Belt: IA, IL, IN, OH, MO
Lake States: MN, MI, WI
Northern Plains: ND, SD, NE, KS
Southern Plains: OK, TX
Delta: MS, LA, AR
Mountain: MT, ID, WY, CO, NM
Pacific: CA, WA, OR
Northeast: PA, NY, MD, DE, NJ, MA, CT, NH, ME
Appalachian: WV, VA, NC, KY
Southeast: GA, SC, FL

Chapter 5

Use of 2,4-D and other Phenoxy Herbicides on Pastureland, Rangeland, Alfalfa Forage, and Noxious Weeds in the United States

RODNEY W. BOVEY[1]

• Table of Comtents

Abstract. About 8.7 million acres of pastureland (8%) are treated in the United States with an estimated 9.3 million pounds of 2,4-D annually at an average rate of 1.1 lb/A for an expenditure of $29.8 million. Loss of 2,4-D would result in considerable acreage of currently treated pastureland not being treated, leading to progressively more serious weed infestations. Current use of 9.3 million pounds of 2,4-D would be replaced by 2.3 million pounds of alternative herbicides, if 2,4-D were banned, and to 2.1 million pounds of other herbicides if all phenoxy herbicides were banned. The principal substitute herbicides would be MCPA if only 2,4-D were banned or dicamba and triclopyr if all phenoxy herbicides were banned. Mowing would be the major non-chemical method of control. Total estimated cost of weed control in pastureland would increase from the current $29.8 to $54.2 million under a 2,4-D ban and to $54.2 million under an all phenoxy herbicide ban. Annual forage loss was conservatively estimated at $330 million under a phenoxy herbicide ban for pastureland. Considering the increased cost of weed control and the value of lost yield, the annual net societal effect from a ban on 2,4-D in pastureland is estimated to be a loss of $383.4 million and the loss from a ban of all phenoxy herbicides to be $384.2 million.

About 4.9 million acres of rangeland (1%) in the United States are treated with an estimated 5.9 million pounds of 2,4-D at an annual expenditure of $16.1 million. Average annual use rate of 2,4-D is 1.2 lb/A. If 2,4-D were unavailable, much rangeland would go untreated. The most probable herbicide alternatives are the same as for pastureland, with more use made of non-chemical methods. The quantification of yield loss in rangeland is difficult, but the annual value of lost forage is conservatively estimated at $64.3 million under a ban of all phenoxy herbicides. The 1992 net societal effect of a ban of 2,4-D in rangeland is estimated to be a loss of $79.5 million and the loss from a ban of all phenoxy herbicides to be $80.4 million.

A ban of only 2,4-D would not effect alfalfa forage production, because only 2,4-DB is used. A ban of all phenoxy herbicides, however, is estimated to cause a 1992 net societal loss of $315 million. A 2,4-D ban for noxious weed control is estimated to cause a 1992 net societal loss of $162 million, and the ban of all phenoxy herbicides would result in a loss of $180 million.

The net societal effect from a ban of 2,4-D in pastureland, rangeland, alfalfa forage production, and noxious weed control is conservatively estimated to be an annual loss of $624.9 million and the annual loss from a ban of all phenoxy herbicides to be $959.6 million.

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INTRODUCTION

Pastureland[2]. Weed scientists from 39 states, representing 77 million acres of pastureland or 73% of total pastureland in 1987, responded to the phenoxy herbicide questionnaire. In addition, task force member estimates of pasture acreage treated for eight additional states brought represented acres to 91% of national acres. A final extrapolation to 100% allowed the estimation of total phenoxy herbicide use in pastureland. Approximately 8%, or 8.7 million acres, were treated with an estimated 9.3 million pounds of 2,4-D annually at a rate of 1.1 lb/A (Table 1) for an expenditure of $29.8 million. An additional 249,000 pounds of MCPA were used nationwide for weed control in pastureland at an average rate of 1 lb/A and estimated total cost of $938,000. Significant use of 2,4-D occurs in Louisiana, Texas, and New Jersey, where between 25% to 30% of pastureland is treated with generally one application of 2,4-D per year. An estimated 20% of pastureland in Nevada and 15% in Alabama, California, Georgia, and Mississippi was treated. According to survey and estimation results, weed control in pastureland was the largest use of 2,4-D in agricultural applications when measured in cost of acid equivalent applied.

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[2] Pastureland is defined as grazing lands planted to primarily introduced or domesticated native forage species, that receive periodic renovation and cultural treatments such as tillage, fertilization, mowing, weed control, and irrigation. Not in rotation with crops (9).

Rangeland[3]. Weed scientists in 30 states, representing approximately 191 million acres of rangeland or 47% of total rangeland acres in 1987, responded to the phenoxy herbicide questionnaire. In addition, task force members provided estimates of rangeland acres treated for 12 additional states to assure comprehensive assessment coverage. Survey data and team member estimates together represented 99.6% of United States rangeland. The combination of survey data and expert opinion estimates indicate that about 4.9 million acres, or about 1% of total rangeland, are treated with 5.9 million pounds of 2,4-D (Table 1) at an estimated annual expenditure of $16.1 million. Average annual use rate of 2,4-D was 1.2 lb/A. States that treated about 3% of rangeland acres included California, Idaho, Nevada, New Mexico, Oklahoma, Kansas, and Florida. States treating 1% to 2% of rangeland acres included Alabama, Arkansas, Colorado, Oregon, South Dakota, Tennessee, and Washington.

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[3] Rangeland is defined as land on which the native vegetation (climax or natural potential.

PHENOXY HERBICIDE REGISTRATION SUMMARY

Both ester and amine formulations of 2,4-D are registered for broadleaf weed control on pastureland and rangeland. On established pastureland, rangeland, and conservation reserve program (CRP) areas, approximately 1 lb/A of the amine formulation of 2,4-D is used on annual is predominantly grasses, grass-like plants, forbs, or shrubs suitable for grazing or browsing use. Includes lands revegetated naturally or artificially to provide a forage cover that is managed like native vegetation. Rangelands include natural grasslands, savannahs, shrublands, most deserts, tundra, alpine communities, coastal marshes, and wet meadows (9).) broadleaf weeds and 1 to 2 lb/A on biennial or perennial broadleaf weeds (1). In CRP areas, 2,4-D is used primarily for control of noxious weeds. Recommended rates for the 2,4-D ester formulation are 1 lb/A to as high as 4 lb/A on certain woody species. The ester formulation is usually preferred for woody plant control because it is slightly more effective and considerably more rainfast than the amine formulation.

Common formulations of 2,4-D amine and ester are the diethylamine salts and the isooctyl ester, respectively, although other formulations are available. The herbicide is applied to the foliage as a spray when broadleaf weeds are small and actively growing, usually in the spring or early summer.

Woody plants are treated when they are actively growing and have developed to the full-leaf stage. Perennial weeds are commonly treated during periods of active fall growth.

For ground application, a minimum of 10 to 15 gallons per acre of water carrier is recommended for adequate spray coverage. For aerial application, a miFor aerial application, a minimum of 2 gallons per acre of carrier is recommended. Livestock should not be grazed on 2,4-D treated areas for 7 days after treatment. Treated areas should not be cut for hay for 30 days after application. Animals being finished for sale are not permitted to graze 2,4-D treated fields

LOSSES DUE TO BROADLEAF WEEDS

Comprehensive studies by Klingman and McCarty (8) on pastureland near Lincoln, Nebraska, established that weed control increased the consumption of vegetation by cattle an average of 20% by mowing but 47% by spraying with 2,4-D. In pastureland treated annually with 2,4-D at 1 lb/A, desirable grasses increased from 1200 to about 2000 lb/A dry matter (8). Grass weeds also increased from about 700 to 1200 lb/A, but weedy forbs decreased in treated areas from 2300 to about 700 lb/A.

Treatment with 2,4-D was clearly superior to mowing for weed control, and mowing reduced total grass production. Plowing, seeding to grasses, and supplemental treatment with 2,4-D was effective in controlling broadleaf perennial weeds. The effect of grazing management had little effect on total production of vegetation. Pastureland deferred and rotationally grazed gave only slightly higher total yield than those grazed as usual.

More vegetation was eaten by livestock in plots having weeds controlled than in untreated areas, and also there was more desirable grass aftermath at the end of the season. Grasses essentially compensated with increased production for the broadleaf weeds eliminated by the 2,4-D treatment.

In other studies, McCarty and Klingman (12) found that mowing for 20 consecutive years did not reduce stands of perennial weeds except for dandelions. Mowing reduced annual weeds by only 30%. Spraying on June 10 or July 5 with 1 lb/A of 2,4-D ester for 20 consecutive years reduced annual and perennial weeds about 90%.

Plowing the sod, seeding forage grasses, and using 2,4-D during and after establishment provided excellent annual and perennial weed control. Consumption of forage from mowed plots was not different from the untreated areas, but use of 2,4-D increased forage consumption by 41% and plowing plus seeding plus use of 2,4-D increased consumption by 58%.

Bade (2) showed that on coastal bermudagrass pastureland in east-central Texas, grass yield for untreated, early 2,4-D application, and early 2,4-D application with fertilizer was 400, 1300, and 2100 lb/A dry matter production, respectively, in a dry year. In a wet year, grass production was 1400, 5000, and 8300 lb/A for untreated, herbicide, and herbicide plus fertilizer treatments, respectively.

In 1965, LeClerg et al. (13) estimated that annual losses in forage production due to weeds on pastureland and rangeland in 31 eastern states was 20%, and 13% for rangeland in 17 western states. Estimated annual loss from weeds in grazing lands for eastern states was $396 million and $236 million for the western states. When the cost of control measures was also included, the total loss for the United States was $1 billion. This estimate is very conservative by 1996 prices and does not include losses from weed problems in establishing forage, or losses from poisonous plants or plants that cause mechanical injury to animals such as from needles and thorns.

In addition to significantly increasing forage production on pastureland and rangeland, 2,4-D can control many poisonous plants. Poisonous plants cause an estimated loss of $245 million annually in cattle and sheep (4). Weeds that are commonly controlled by 2,4-D in grazing lands are hay fever weeds, such as ragweed; weeds with spines and thorns, which cause injury to humans and animals; and weeds that render milk unusable because of taste.

Bentley (3) in 1967, reported that conversion of chaparral to grass in California was least expensive with 2,4-D and 2,4-5-T as compared to other methods, although some undesirable species were moderately tolerant and required several herbicide applications. The most difficult phase of the rangeland conversion process was establishment of perennial grasses.

Hoffman (7) increased the grazing potential for cattle from 67 animal units to 178 on 1000 acres after spraying 2,4-D on Macartney rose-infested pastureland in southeast Texas. The unsprayed area produced an average of 2500 lb/A of forage; whereas, the sprayed area produced 5300 lb/A.

CURRENT CONTROL METHODS

Weeds and brush on pastureland and rangeland can be controlled by herbicides, prescribed burning, mechanical methods, or by biological means (5). Herbicides are applied to foliage (sprays) or roots (sprays or pellets), depending upon the weed species to be controlled and the herbicide used. Sprays are applied broadcast at ultra low, low, or high carrier-volumes to weeds and brush with hand-carried equipment, ground equipment, or aircraft. Selection of application equipment depends on the density of weeds and brush, the weed species, and the acreage to be covered. In many cases, rough terrain and tall vegetation limit the use of ground or hand-carried equipment; so aircraft generally are used, especially on large areas.

Where stands are scattered, individual plants can be treated with herbicides by foliar sprays, cut surface and injection treatments, and soil treatments. Special wiping devices also are used to treat individual plants in small or scattered stands of weeds and brush in noncrop areas, around buildings, vacant lots, roadways and similar areas, or for maintenance of control following other practices.

All application equipment must be calibrated to deliver the proper amount of herbicide. Too little herbicide will result in poor results, and too much will be costly and may injure desirable vegetation. Also, the user must apply the herbicide during the most favorable time for control.

Mechanical control includes hand methods such as sawing, axing, girdling, and grubbing woody plants. Hand methods are costly, hazardous, and laborious and can be used only for small areas. Extensive acreages require large equipment for dozing, chaining, railing, chopping, mowing, root plowing, or disking. Selection of method is determined by available equipment, weed species and density, type of land, and terrain.

Biological control is possible with selective grazing by cattle, sheep, goats, horses, poultry, and certain wildlife species. Insects and plant pathogens are effective for biological control of some weed species. Prescribed burning to control weeds and brush on grazing lands is systemically planned to meet specific management objectives (14). For safety and to obtain good results, burning should be done by an expert.

Combinations of two or more control measures may be less costly and more effective than a single method. Deciding when to control weeds or brush sometimes is difficult because many factors must be considered. Recognizing a potential weed problem and controlling it before it spreads and becomes a serious pest is the best approach. Reseeding may be necessary after controlling weeds and brush, because native forage plants may be too sparse to produce adequate forage for livestock production.

COST OF CONTROL METHODS

The cost of 0.5 lb/A of 2,4-D amine is about $1.40 per acre. The ester of 2,4-D is about $1.75 for 0.5 lb/A. Alternative phenoxy herbicides, such as MCPA, would be similar in cost to 2,4-D ester. Cost of alternative herbicides at 0.5 lb/A would be about $9.50 for dicamba, $27.50 for picloram, and $10 for triclopyr. Cost per pound of picloram is over twice that of dicamba or triclopyr. Alternative chemicals would be at least five times more expensive than 2,4-D at standard per-acre-use-rates. Costs indicated do not include application expenses.

Mechanical control such as roller chopping costs about $25/A but has only a temporary effect, and bulldozing is $45 to $60 per hour for woody plant control. Mechanical methods are expensive and sometimes destroy the foper hour for woody plant control. Mechanical methods are expensive and sometimes destroy the forage species allowing soil erosion. Mechanical treatments may also create a seedbed for weed establishment. Mechanical methods are impractical on rocky or steep terrain. Hand methods are costly, laborious, and are confined to small areas. Costs

Mowing and shredding are temporary control methods for herbaceous weeds and small brush on grazing lands. Repeated mowing once or twice per year is needed for suppression of most weeds. Cost is about $10.75/A for one mowing. Mowing does not kill herbaceous or woody perennials in grazing lands but helps prevent production and spread of weeds.

Selective grazing for control of undesirable weeds and brush is a widely used practice. Cattle, sheep, goats, horses, poultry, and certain wildlife species control many weeds by grazing. In other cases grazing is not effective because weeds may be unpalatable, poisonous, or tenacious. Management of weeds by grazing appears inexpensive but may require expensive fencing and protection from adverse weather and predators to prevent severe economic loss, especially with sheep and goats.

Insects and pathogens have very limited and unpredictable use at this time for weed and brush control on grazing lands. Control by this means may be economical once the research and development of the organism has been accomplished.

Prescribed burning costs will vary widely depending upon management experience with prescribed burning and the method used (14). Costs are associated primarily with labor and equipment requirements. Prescribed burning is a complex operation and should be done by experts. Prescribed burning does not replace herbicide use for control of weeds. In fact, herbicides often are used before or after burning to desiccate species which facilitates burning or to control weeds that emerge after burning. Burning is not possible where fuel is not sufficient or where succulent vegetation prevails. Burning costs vary from $1.50 to $3.00/A, with lower costs associated with burns on large acreages. Smoke management regulations severely restrict agricultural burning in some areas, and future use of prescribed burning may be a questionable practice.

IMPACT OF THE LOSS OF 2,4-D

Pastureland. The loss of 2,4-D for pastureland applications would result in considerable acreage receiving no treatment for weed control and degradation of the resource. About 70% of currently treated acres in Oklahoma and Montana would go untreated without 2,4-D as would 60% in Nevada, and 30% in Nebraska and Washington. Herbicide applications on acres currently being treated with 2,4-D would decrease from 9.3 million pounds to 2.3 million pounds if other phenoxy herbicides remained in use and to 2.1 million pounds if all phenoxy herbicides were banned.

Rangeland. Should 2,4-D be unavailable for use on rangeland, many states report that significant acreage would receive no weed control treatment. For instance, in Montana, 75% of acres currently being treated with 2,4-D would go untreated, as would 60% of such acres in Tennessee, 50% in Nebraska, and 20% in Kansas. Amount of herbicide applied would decrease from 5.9 million pounds to 1.4 million pounds.

WEED CONTROL ALTERNATIVES IF 2,4-D WERE LOST

Pastureland. If 2,4-D were banned and other phenoxy herbicides remained in use, MCPA would replace 2,4-D on 12% of currently treated acres. Dicamba would be substituted on 41% of the acreage, and triclopyr (30%), picloram (5%), glyphosate (5%), and paraquat (3%) would also be used.

Rangeland. The most probable alternatives to replace 2,4-D, by percent of currently treated rangeland acres, include dicamba (54%), picloram (21%), MCPA (15%), and triclopyr (9%).

IMPACT OF THE LOSS OF ALL PHENOXY HERBICIDES

Pastureland. If all phenoxy herbicides were banned, dicamba would comprise 47% of substitute herbicides used, triclopyr 34%, and picloram 5%. Cost of weed control using both chemical and non-chemical methods would increase from the current estimated $29.8 million expenditure on

2,4-D to $53.4 million under a 2,4-D ban and to $54.2 million under an all phenoxy herbicide ban. Included in the alternative costs are $12.7 million for non-chemical weed control methods, which consist mainly of mowing of pastureland. Other non-chemical methods include burning, handcutting, livestock grazing, and biological control (reported in North Dakota and Wyoming).

Significant yield loss in many states was expected if phenoxy herbicides were unavailable: Oklahoma 38%, Hawaii 30%, Tennessee and Washington 25%, Louisiana and Missouri and Montana 20%, Texas 15%, and Florida 10%. Data from field studies at various United States locations indicated that gains of 1000 pounds of dry matter production per acre, or more, are common using 2,4-D to control weeds on grazing lands. If 8.7 million acres of pastureland were not treated with phenoxy herbicides as estimated in our survey, we could assume an average loss of at least 1000 pounds dry forage per acre or 4.4 million tons. If one ton of dry forage is worth $75, then losses would be $330 million annually. These values are conservative because not all treated acres may be reported, and forage loss without phenoxy herbicides probably is higher than estimated. Costs do not include alternative methods or degradation of resources without treatment, but most respondents indicated that without 2,4-D, most acres would go untreated. Therefore, the economic impact of losing the phenoxy herbicides for use in pastureland weed control is measured as the cost of alternative chemical materials and non-chemical weed control methods plus the cost of estimated forage loss. In addition, there is cost implicit in abandoning practices that have been in development for over 4 decades. This may result in public mistrust of extension and regulatory agencies and increased hesitancy to adopt new procedures. There would be long-term costs affecting operations as well as loss of productivity and resource degradation with a phenoxy herbicide ban.

Costs per treated acre of pastureland would increase by $6.12 with overall production costs increasing by $54.2 million (Table 2), the aggregate cost of alternative weed control methods. Net revenue would decrease by the same $54.2 million, the cost increase. Yield losses are estimated at $330 million annually. - If all phenoxy herbicides were banned, the net societal loss is estimated to be $384.2 million.

Rangeland. If all phenoxy herbicides were banned, alternative herbicide use would total approximately 1.4 million pounds. These alternatives herbicides would be dicamba (66%), picloram (23%), and triclopyr (10%). Total costs for chemical control would increase from $16.1 million currently spent on 2,4-D to $32.5 million under the loss of 2,4-D scenario, and $33.4 million if all phenoxy herbicides were lost.

Non-chemical weed control alternatives mentioned most often include burning and mowing on rangeland, but these methods are not practical on most rangeland sites in the West. The North Dakota respondent indicated that biological control of leafy spurge and thistles would be used on 10% of treated acres. Non-chemical controls on treated acres in responding states would total about $1.5 million.

A number of state respondents indicated that significant forage yield loss would result if phenoxy herbicides were banned. This loss would be 20% in Montana and Oregon; 10% in Colorado, Floridaloss would be 20% in Montana and Oregon; 10% in Colorado, Florida, and Kansas; and 5% in Nebraska and North Dakota. On United States rangelands one could assume at least an average of 350 lb/A loss of forage under a phenoxy herbicide ban. If 4.9 million acres of rangeland, as estimated in our survey, were treated with less effective alternatives, losses of 857,000 tons of dry forage could be expected. If one ton of forage is worth $75, then annual losses would be $64.3 million. This loss estimate is conservative because the costs of alternative weed control methods were not considered. It also does not consider such things as weed problems in forage establishment; or problems with plants that are poisonous, cause allergies, m

The economic analysis reflects acreage represented in the responding states as well as acreage estimates made by task force members from non-responding states. Costs per treated acre would increase by $3.29/A with overall production costs increasing by $16.1 million (Table 2). Net revenue would decrease by the same amount, $16.1 million. The consumer effects are estimated as the loss in forage of $64.3 million. Therefore the net societal effect is a loss of $80.4 million. The deterioration of the rangeland resource, if grazed without controlling weeds and brush, is not included in this estimated loss.

WEED CONTROL ALTERNATIVES IF ALL PHENOXY HERBICIDES WERE LOST

Pastureland. Alternative herbicides that would be used if all phenoxy herbicides were banned include dicamba on 47% of currently treated acres, triclopyr on 34%, and picloram on 5%. Use of non-chemical weed control methods also would increase if phenoxy herbicides were banned.

Rangeland. Weed and brush control alternatives that would be used if all phenoxy herbicides were banned include dicamba on 66% of currently treated acres, picloram on 23%, and triclopyr on 10%. Use of non-chemical control methods would increase, but at a considerable increase in cost.

COMPELLING REASONS THAT SHOULD PREVENT THE LOSS OF THE PHENOXY HERBICIDES

For herbaceous and woody plant control on pastureland and rangeland, 2,4-D is by far the most economical and environmentally safe herbicide available. It provides desirable ecological shifts from undesirable to desirable vegetation and improves vegetation cover for erosion control, wildlife habitat, and watershed management. It increases available livestock and wildlife forage and reduces harmful and poisonous plants. It is useful in the establishment of new seedings and revegetation practices. The phenoxy herbicides are short lived in the environment and residues in food and water sources are very unlikely. The herbicide, 2,4-D, can be used to manage a broad- spectrum of broadleaf weeds including some woody plants. These characteristics do not exist for other herbicides at costs commensurate with benefits derived. The phenoxy herbicides, including 2,4-D, are essential tools in pastureland and rangeland management.

The herbicide, 2,4-D, has been used on pastureland and rangeland for selective control of herbaceous weeds and brush for 51 years. It is one of the most environmentally safe and most economical herbicide treatments available. Weed control in pastureland is the major use of 2,4-D in the United States. Both ester and amine forms of 2,4-D are used. If 2,4-D were banned, MCPA would be used on 20% of the acres currently treated with 2,4-D, but most of the pastureland would go untreated. If all phenoxy herbicides were banned, more costly herbicides including dicamba, picloram, and triclopyr would be used but on a limited basis. Non-chemical weed control methods including mowing would increase in use on flat pasturelands, but on a limited basis. Cost for weed control without phenoxy herbicides would greatly increase as would the spread of broadleaf weed infestations.

On rangelands, only a small percentage of the acreage is treated, but 2,4-D is an important economical treatment on certain weeds and woody plants. If 2,4-D were banned, much of the treatable acreage would not be treated even though prescribed burning and mechanical methods are available. Alternatives to phenoxy herbicides for rangeland are similar to those for pastureland.

WEED RESISTANCE MANAGEMENT WITH THE PHENOXY HERBICIDES

Some weed resistance has been reported for the sulfonylurea and triazine herbicides on pastureland and rangeland. The author is unaware of any reports of weed resistance to herbicides from long-term use of 2,4-D on grazing lands, perhaps because repeated use of herbicides on the same areas is infrequent.

FUTURE WEED MANAGEMENT OPTIONS

The need to manage and manipulate weed populations on pastureland and rangeland will not diminish. Weed problems will continue to dominate and will not be replaced with desirable vegetation without continued weed management efforts. One only has to consider the eminent infestations on grazing lands of noxious weeds and such brush as honey mesquite, junipers, pricklypear cactus, halogeton, leafy spurge, knapweeds, yellow starthistle, and many others to realize their persistent nature and widescale spread. Many of these weeds are exotics and have little redeeming ecological value. Most alternative herbicides or non-chemical methods are too expensive to use on grazing lands except on the more productive sites. The herbicide, 2,4-D, is the only chemical control method that can justifiably be used on most of these areas because of its low cost and environmental safety. If 2,4-D were not available, many acreages would simply go untreated, leading to further weed and brush encroachment on millions of acres of grazing land each year.

ALFALFA FORAGE

The only phenoxy herbicide used for weed suppression in alfalfa production is 2,4-DB. About 2 million acres of alfalfa are treated annually, which represents about 8% of represented alfalfa acreage in the phenoxy herbicide survey. About 93% of total alfalfa acres were represented by the states responding to the survey. Extrapolation brought coverage to 100%. Percent of acres treated varied greatly by region in the United States. Approximately 80% of acreage in the Delta states are treated with 2,4-DB; the Pacific States report 22% of acres treated and the Southeast 14%. An estimated 1.5 million pounds are applied at an average rate of 0.76 lb/A (Table 3) with an annual expenditure of $28 million.

If phenoxy herbicides were banned from alfalfa production, growers would substitute bromoxynil on 38% of treated acres, EPTC on 30%, paraquat on 20%, metribuzin on 7%, and the remaining 5% would receive treatments with a variety of other herbicides. About 1.1 million pounds of herbicide alternatives would be used at an estimated expenditure of $15.8 million. This decrease in chemical herbicide use is attributed to respondents' predictions that a large amount of currently treated acreage would go untreated. For instance, 100% of currently treated acres in Illinois, Georgia, Connecticut, Delaware, and Massachusetts would have no alternative weed control method or herbicide applied. Significant acreage in Kentucky (80%), Oklahoma (77%), Nebraska and Michigan (60%), and Minnesota (30%) would also go untreated. Respondents indicated that virtually no non-chemical alternative weed control method would be used in alfalfa.

Alfalfa yield losses of up to 30% would occur without 2,4-DB in Tennessee and Oregon, 20% in Georgia, and 15% in Wisconsin and Connecticut. Significant regional impacts include a 16% loss on treated acres in the Southern Plains, 14% in the Pacific States and the Southeast, 10% in the Delta, and 7% in the Lake States. The weighted-average yield loss was estimated to be 5.2%.

The AGSIM simulation model (15) uses a price elasticity of demand estimate of -0.512 for alfalfa and other hay used in domestic feed.[4] This value combined with the aggregate yield loss estimate results in a predicted farm-level price increase of 1.3%. The resulting loss in consumer surplus was estimated at $81 million. Costs of production would actually decrease by $18.9 million (Table 4) for the following reasons: (a) fewer acres being treated, and (b) substitution of generally less expensive, though less effective, herbicides for 2,4-DB. Costs of alfalfa production per treated acre were estimated to decrease by $9.52. Net revenue, however, was predicted to decline by as much as $234 million because of the yield loss. Per acre revenue decrease on treated acres was estimated to be $1.08, which is considerably mitigated by the decrease in costs per treated acre of $9.52, as reported above. Growers with untreated acres could see a per acre revenue increase of $3.46. Phenoxy herbicide users in the Pacific, Delta, and Southern Plains states could experience losses of up to $32/A while growers in the Corn Belt, Northeast, and Appalachian states could see revenue increases of up to $5/A. Nationwide, non-users of phenoxy herbicides in alfalfa would experience per acre revenue increases; up to an estimated $5.19/A in the Pacific states. The annual net societal loss of a phenoxy herbicide ban in alfalfa production is estimated as $315 million.

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[4] Taylor, C.R. 1994. Personal communication. Dep. Agric. Econ., Auburn Univ., Auburn, AL 36849.

NOXIOUS WEED CONTROL

Noxious weeds are undesirable plant species that are designated by law as undesirable and managed so as to control or eradicate them. Federal and state pure seed laws have been enacted that prohibit or limit sale of crop seeds containing noxious weed seeds. State and federal weed control laws also exist that require control of designated noxious weed species growing on private and public lands. Results of this survey indicated that most noxious weed acreage is treated with 2,4-D, with minor use of MCPA, 2,4-DP, picloram, or dicamba.

The Nebraska respondent reported that about 2.2 million acres were treated with 2,4-D in 1992 at a cost of $16.5 million for noxious weed control. Average treatment rate was 1.5 lb/A with 1.2 treatments per year. Major alternative herbicides included picloram and dicamba, if 2,4-D were not available, but picloram and dicamba would cost at least six times more per acre than 2,4-D.

Non-chemical control methods would be used on about 15% of the total acres now treated and about 50% of the total acres infested would receive no treatment if 2,4-D were banned.

In South Dakota, 2.1 millon acres were treated in 1992 with 2,4-D and an additional 10,000 acres were treated with MCPA for noxious weed control. Cost of 2,4-D treatments was $19.5 million and $0.5 million for MCPA treatments. Average treatment rate was 1.1 lb/A of 2,4-D with 1.1 treatments per year. Major substitute herbicides would include glyphosate, picloram, dicamba, and clopyralid if 2,4-D were banned. Tillage would be used on 10% and mowing on 15% of acreage currently being treated with 2,4-D if this herbicide were not available. If phenoxy herbicides were not available, no substitute control method would be used on 10 to 15% of the area currently treated.

In Kansas, over 1 million acres were treated with 2,4-D in 1992 at a cost of $6 million. Average rate of 2,4-D applied was 1.25 lb/A with 1.2 treatments per year. Major alternative herbicides included picloram, dica1.25 lb/A with 1.2 treatments per year. Major alternative herbicides included picloram, dicamba, and metsulfuron. Minor use

In Missouri, estimated acres treated annually with 2,4-D were 47,000 at a cost of $0.6 million with an additional 12,000 acres treated with 2,4-DP at a cost of $0.2 million. Each herbicide was applied once per year at 2 lb/A. Major alternative herbicides included glyphosate, picloram, and dicamba. Minor use of non-chemical control methods were indicated, if 2,4-D were banned.

Estimated acreage treated annually in Idaho with 2,4-D, MCPA, and 2,4-DP was 34,000, 15,000, and 1,000 acres, respectively. Application costs were $0.4 million for 2,4-D, $0.5 million for MCPA, and $0.01 million for 2,4-DP. Main herbicides to be used if 2,4-D were lost included MCPA, 2,4-DP, dicamba, and clopyralid, with mowing indicated as the main non-chemical method of weed control. If all phenoxy herbicides were lost, dicamba would be the main herbicide used. There would be no substitute control method used on 25% of the acreage currently treated if all phenoxy herbicides were lost.

In Minnesota, 29,000 acres were treated with 2,4-D at a cost of $0.5 million. An additional 11,600 acres were treated with 2,4-DP at a cost of $0.3 million. Average rate of 2,4-D was 1.6 lb/A and 2,4-DP was 1.5 lb/A. Average number of treatments per year for 2,4-D was 1.1 while 2,4-DP was used once. Picloram was also used on 15,000 acres as a spot treatment. Main alternative herbicides to 2,4-D included MCPA, 2,4-DP, picloram, and dicamba. If all phenoxy herbicides were banned, the main substitute herbicides would be glyphosate, picloram, dicamba, and clopyralid. The principal non-chemical treatment was mowing, and if no phenoxy herbicides were available, 10% of the currently treated acres would receive no substitute control method.

The Delaware respondent reported 20,000 acres treated with 2,4-D once per year at 1 lb/A at a cost of $0.15 million. Main substitute chemicals included glyphosate and dicamba with no use of non-chemical methods.

Virginia, Maryland, and Kentucky reported 3,000, 3,600, and 6,800 acres treated with 2,4-D, respectively, at a cost of $0.15 million. All three states treated an average of once per year with 1, 1.5, and 2 lb/A for Maryland, Virginia, and Kentucky, respectively. The likely substitute herbicides for Virginia were dicamba and clopyralid if 2,4-D were lost. The probable alternatives to 2,4-D for Kentucky were dicamba and metsulfuron. Glyphosate, dicamba, clopyralid, and tribenuron were alternatives for Maryland. Mowing was an alternative predicted to be used on 8% of the currently treated acreage in Kentucky and 20% in Virginia.

In Idaho, Canada thistle, whitetop, Dalmatian toadflax, field bindweed, yellow starthistle, and the knapweeds are noxious weeds. In Minnesota, Canada thistle, perennial sowthistle, musk thistle, plumeless thistle, purple loosestrife, and leafy spurge are major noxious weeds. Musk thistle, leafy spurge, and field bindweed are common noxious weeds in the Great Plains states.

In North Dakota, the most cost effective treatment for leafy spurge was picloram plus 2,4-D at 0.25 plus 1 lb/A (11). Alternatives to picloram plus 2,4-D are usually prohibitively expensive. In North Dakota, lost animal unit months on 11 million acres infested with leafy spurge represented a loss of $78 million on grazing lands with another $8 million for wildlife losses for a combined total loss of $86 million (10). Economic losses from leafy spurge infestations on grazing land and hay land in North Dakota, South Dakota, Montana, and Wyoming was about $129.5 million annually.

Frandsen and Boe (6) indicated noxious weeds on grazing lands caused losses exceeding $340 million in 1989 in the 17 western states. This includes losses only on rangelands.

Based on data from our survey, in which most states did not report any spraying of noxious weeds, an estimated average of 0.2 million acres are treated annually in each state with a Noxious Weed Program. Because 35 (70%) of the states have noxious weed programs, total acres treated would be about 7 million. If 75% of that area was treated with 2,4-D, cost for application would be about $54 million. If alternative herbicides were used, control costs could increase six, or more, times or no herbicide would be used on up to half of the present treated area. Mowing and cultivation of noxious weeds would be used on 10% or less of the currently treated areas, with inconsistent results. Some states reported limited use of other phenoxy herbicides. Nebraska, Kansas, Delaware, Maryland, Virginia, Kentucky, and North Dakota indicated no alternative phenoxy herbicide use to 2,4-D. Alternative phenoxy herbicides would have limited, or no use in most states.

Without 2,4-D, one could assume average annual increased control costs of at least three-fold or $162 million over current cost, or $180 million if all phenoxy herbicides were banned.

One annual 2,4-D treatment at 1 to 2 lb/A is usually applied for noxious weed control. Loss of 2,4-D would result in many infestations not being treated, or treated with inadequate control practices, greatly accelerating resource degradation, or they would be treated with more expensive methods at greatly increased public costs. Because alternative phenoxy herbicides do not control many noxious weeds and because cost-effective non-phenoxy herbicides are not available, it is important that 2,4-D be retained for noxious weed management in the United States.

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Tables 1-4 from Chapter 5

Table 1. Yearly production and phenoxy herbicide use on pastureland and rangeland in the United States during 1992.

Crop and herbicides	Acres in production[a] (000)	Acres treated (000)	Acres treated %	Phenoxy herbicide use Pounds used (000)
Pastureland	105,532			
2,4-D		8,731	8.3	9,330
MCPA		249	0.2	249
Rangeland	410,328			
2,4-D		4,899	1.2	5,867
Total	515,860	13,879	2.7	15,446

[a] Based on data for 1987.
[b] Based on 1993 survey of 1992 data.

Table 2. Estimated increased weed control costs in pastureland and rangeland in the United States during 1992 with the loss of all phenoxy herbicides.[a]

Crop	Loss per treated acre[b]	Total loss
	$	$ (000)
Pastureland	6.12	54,200
Rangeland	3.29	16,100

[a] Most phenoxy herbicide involved was 2,4-D. The relatively small amount of MCPA used in pasture (shown in Table 1) has not been separated from 2,4-D in this table.
[b] Refers to acres estimated to have been previously treated with any phenoxy herbicide.

Table 3. Yearly production, price, and phenoxy herbicide use for alfalfa forage in the United States during 1992.

Crop and	Acres in	Production and	Price per	Phenoxy herbicide use

herbicide	production[a] (000)	yield units (000)	unit $	Acres treated (000)	%	Quantity lb(000)
Alfalfa forage	25,659	81,573 ton	77.82			
2,4-DB					1,985	7.7

[a]Average for years 1989 to 1991.
[b]Based on 1993 survey of 1992 data.

Table 4. Estimated production and weed control cost increases in alfalfa forage during 1992 with the loss of all phenoxy herbicides in the United States.[a]

Crop	Production loss: Quantity and yield unit	Production loss: Proportion of total	Weed controlcost changes: Control cost per treated acre[b]
	(000)	%	$
Alfalfa hay	4,242 ton	5.2	-9.52

[a]The only phenoxy herbicide used was 2,4-DB.
[b]Refers to acres estimated to have been previously treated with 2,4-DB.

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Chapter 6

Phenoxy Herbicide Use in Field Corn, Soybean, Sorghum, and Peanut Production in the United States

ELLERY L. KNAKE[1]

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Abstract. Phenoxy herbicides are currently used in field corn, soybean, sorghum, and peanut production in the United States for controlling broadleaf weeds. Weed scientists or crop production specialists in all states were contacted to estimate the impact during 1992 on the production of these four crops if either 2,4-D or all phenoxy herbicides were no longer available. The phenoxy herbicide, 2,4-D, has been used by growers for 51 years; it and other phenoxy herbicides have become an integral part of weed management programs. Although 2,4-D use peaked in corn with over 50% of the acreage being treated in the 1950's, use has declined now to about 11% of the corn acreage. However, with an increasing acreage of no-till corn there has been a concomitant increase in use of 2,4-D for control of existing weeds and cover crops prior to planting. In soybean, 2,4-DB is used postemergence to a limited extent, but 2,4-D is being increasingly used for preplant weed control in no-till soybean production. In sorghum, 2,4-D is used as a postemergence treatment in the crop and for preplant weed control in no-till systems. In peanut production, 2,4-DB has been used as a postemergence treatment on about 83% of the United States acreage. In all four crops, phenoxy herbicides have been effective in providing economical control of many annual and perennial broadleaf weeds. Of the various alternative herbicides that are currently available, or are expected to become available, none match the relatively low cost of the phenoxy herbicides. Increased tillage might be used to replace phenoxy herbicides, if they were no longer available; but, farmers are striving to reduce tillage rather than increase it. Respondents estimated for 1992 that, in corn, the effect of the loss of 2,4-D (the only phenoxy herbicide used for corn) would be an annual net societal loss of $246 million. The loss of both 2,4-D and 2,4-DB (the only two phenoxy herbicides used for soybean) was estimated to be an annual net societal loss of $155 million. For sorghum, the effect of banning 2,4-D (the only phenoxy herbicide used for sorghum) was estimated to be an annual net societal loss of $30.7 million. For peanut, the effect of banning 2,4-DB (the only phenoxy herbicide used for peanut) was estimated to be an annual net societal loss of $139 million.

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INTRODUCTION

Field corn, soybean, sorghum, and peanut are crops in which phenoxy herbicides provide economical, efficacious, and environmentally advantageous weed control. Data on phenoxy herbicide usage, projected losses in the event of cancellation of registration of 2,4-D or all phenoxy herbicides, alternative herbicides or other alterative weed control practices, changes in crop production, and reasons for retaining phenoxy herbicides were obtained from a questionnaire sent to selected weed scientists or crop production specialists. Data from this survey were extrapolated to represent 100% of the total acres for each crop. Response to the questionnaire was excellent but some extrapolation was necessary before entering the survey data in the AGSIM model (discussed in Chapter 4).

The use of 2,4-D for controlling broadleaf weeds in corn has a 50 year history (Figure 1). One of the first large-scale trials was in 1947 for control of giant ragweed in corn in Henderson County, Kentucky (1). The selective action of 2,4-D was considered a fantastic development, and use of 2,4-D for control of broadleaf weeds in corn expanded rapidly in the late 1940's and early 1950's with over half of United States corn acreage being treated. In addition to being very selective and effective, 2,4-D was quite economical. With the advent of other herbicides since the 1950's, use of 2,4-D gradually declined, but it still remains an important part of weed control for corn. Survey results show that 11% of the nearly 74 million acres of corn were treated in 1992 with 2,4-D (Table 1). The increase in no-till corn production during the 1990's versus plowing (Figure 2) has increased use of 2,4-D because it is one of the most effective and it is the lowest cost herbicide for controlling many of the annual, winter annual, biennial, and perennial weeds present in no-till fields in the spring prior to planting.

The most important use of phenoxy herbicides for soybean in the mid 1990's is that of 2,4-D to control existing vegetation prior to planting no-till soybean. Acreage of no-till soybean has increased dramatically in recent years, partly to help farmers comply with federal plant residue mandates for soil conservation and partly to reduce production costs. Use of 2,4-D prior to planting has been a major factor in making no-till feasible.

There has been some use of 2,4-DB postemergence in soybean, especially for control of such important weeds as common cocklebur, giant ragweed, ivyleaf morningglory, and tall morningglory. It is quite low in cost and is sometimes added to other herbicides to broaden the spectrum of weed control. However, 2,4-DB sometimes causes injury to soybean, with damaged plants exhibiting distorted and proliferated growth. As more selective herbicides for soybean became available in the 1980's, use of 2,4-DB declined. Although 2,4-DB is also registered for use prior to planting no-till soybean, this use has not become very popular, because 2,4-D is less expensive and more effective for the same purpose (5, 7, 12).

Sorghum is produced under both dryland and irrigated conditions. Dryland production accounts for 81% and irrigated for 19% of sorghum acreage (11). There are two types of sorghum, grain sorghum that is grown primarily for its grain that is fed to livestock and forage sorghum where the entire above-ground portion of the plant is used for livestock feed (2). Weeds are generally not a very significant problem in solid-seeded forage sorghum because the high population of sorghum plants usually provides dense shade and significant competition for weeds. Thus, herbicides are of less importance for forage sorghum, and there are fewer herbicide options registered as compared to grain sorghum.

Grain sorghum is grown in rows and the plants are relatively short. This facilitates combining, but means less competition from the sorghum and more opportunity for weeds to grow. Because the plants are grown in rows, weeds in the row can be a problem. Grain sorghum is generally cultivated once or twice (11), but that may not always result in adequate control of weeds in the row. Thus, the need for herbicides, which are currently used on 96% of United States grain sorghum acreage (11, 15). Our survey showed 2,4-D to be used on about 11% of the sorghum acreage (Table 1).

Peanut is not a large acreage crop in the United States, but it is an important crop economically. There are nearly 2 million acres of peanut produced, with a total production of a little over 4 billion pounds (Table 1). Peanuts are formed underground, and the tops of the plants do not grow very tall or produce a lot of canopy to shade or compete with weeds (9). Peanut is grown in rows, and weeds are a major production problem. Cultivation is feasible for controlling weeds between peanut rows, but it is limited in order to prevent disturbing the underground harvestable portion of the plants. Thus, herbicides have been especially helpful for controlling weeds in the row out of reach of the cultivator (4, 14). The phenoxy herbicide, 2,4-DB, is an important tool in peanut production, being used in 1992 on about 83% of the total United States acreage (Table 1).

PHENOXY HERBICIDE REGISTRATION SUMMARY

Field corn. Before the advent of some of the other soil-applied preemergence herbicides in the 1950's, research was conducted with use of 2,4-D as a preemergence herbicide for corn. Some 2,4-D formulations are still registered for this use. At high rates of 1.5 to 2 lb/A applied preemergence, 2,4-D can selectively control weed seedlings soon after germination. At these high rates, 2,4-D can even provide some control of annual grass weeds. As more selective soil-applied herbicides became available in the late 1950's and early 1960's, preemergence use of 2,4-D declined. Ester formulations of 2,4-D were recommended for preemergence soil application because they are less soluble and hence less likely than amine salts to leach and cause corn injury.

The major use of 2,4-D in corn has been as a postemergence herbicide for control of broadleaf weeds (Figure 3). It is commonly applied broadcast over the top of corn, but after corn becomes about 8 to 10 inches tall, use of "drop nozzles" is recommended so the application is directed onto the weeds and kept out of the corn leaf whorl to decrease risk of crop injury (Figure 4).

Labels for 2,4-D include information on application timing and crop injury potential. Injury to corn can be expressed as tightly rolled leaves, referred to as "onion-leafing." Corn brace roots may become fused and flattened. Cornstalks may become brittle following 2,4-D spraying and may break, especially during strong winds. Corn plants may lean over and then try to become erect, causing a condition called "elbowing." It is recommended that 2,4-D not be applied when corn is tasseling or silking because this can interfere with fertilization or setting of kernels on the ear. After the corn kernels are in the dough to dent stage, preharvest application of 2,4-D can be made without significant risk of corn injury. However, this is not very common because by that time weeds are usually relatively large and more difficult to control, weeds have already caused yield reduction, use of ground spray equipment may not be practical, and use of aerial spray equipment may pose too much risk of 2,4rolled le

The most commonly used formulations of 2,4-D are amine salts and low volatile esters. There is limited use of high volatile esters. Granular formulations of 2,4-D previously were used preemergence but now are seldom used for corn. Dust formulations were introduced, but drift was a serious problem and use of dusts ceased. More recently, some dry soluble formulations have become available which offer some convenience and about equal performance as compared to other formulations.

Soybean. Both the ester and amine formulations of 2,4-D are registered for use prior to planting no-till soybean to control established broadleaf weeds. If low volatile ester is used, approximately 0.38 to 0.5 lb/A can be applied not less than 7 days prior to planting, but 0.5 to 1 lb/A may be used if applied not less than 30 days prior to planting. Registration for the amine formulation of 2,4-D is similar except the 0.38 to 0.5 lb/A is to be applied not less than 15 days prior to planting. However, from a practical viewpoint, the ester is commonly used because it is less soluble than the amine and less likely to leach in the soil and cause soybean injury. Registration of 2,4-D includes mixtures with several other herbicides for preplant application for no-till soybean.

The major formulations of 2,4-DB are dimethylamine salts. Compared to 2,4-D, the 2,4-DB has the flexibility of application before planting or before soybean emergence, using a rate of 0.175 to 0.225 lb/A. For postemergence application, 2,4-DB may be applied broadcast over the top of soybean or as a directed band.

For preplant application, 2,4-DB may be used in combination with such herbicides as paraquat, glyphosate, pendimethalin, imazethapyr, and imazaquin. Postemergence directed band applications include combinations with linuron or metribuzin. Other combination partners for postemergence use include acifluorfen, fomesafen, imazethapyr, chlorimuron, and imazaquin.

Postemergence broadcast application of 2,4-DB is labeled only for southern states and does not include the states of Iowa, Illinois, Indiana, Kansas, Michigan, Minnesota, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin, and parts of Kentucky and Missouri.

Sorghum. The only phenoxy herbicide used for grain sorghum is 2,4-D. It may be used prior to planting to control weeds and broadleaf cover crops in preparation for no-till sorghum. Often 2,4-D is used in combination with glyphosate for this purpose. It may also be used for weed control during fallow periods. However, the major use of 2,4-D for sorghum is postemergence for control of broadleaf weeds.

Peanut. As with some other legume crops, peanut is not tolerant to postemergence applications of 2,4-D, but 2,4-DB has been used postemergence in peanut for many years. The labeled rates are 0.22 to 0.4 lb/A, but the average use rate is 0.38 lb/A.

LOSSES FROM BROADLEAF WEEDS

Field corn. Considerable research has been done to determine the effect of weeds on corn yields (Figure 4). The term "competition" was formerly used predominantly to indicate that weeds compete with corn for moisture, nutrients, and light. More recently, the term "interference" has become more popular and includes the influence of allelopathy or toxic substances from weeds.

Methods are available to determine the degree of infestation and crop yield loss thresholds for various weed species. Yield reductions caused by weeds have been determined and can range up to 100%, depending on such factors as weed species, weed intensity, time of weed emergence, time and duration of interference, production practices, weather conditions, and weed control methods. As a "rule of thumb," each unit of energy that goes into weeds cannot go into the crop and crop yields are reduced proportionately (10).

Weed species vary significantly in sensitivity to 2,4-D. Pennsylvania smartweed and jimsonweed can show epinasty or malformation but are not easily killed with 2,4-D. However, ivyleaf morningglory, tall morningglory, common cocklebur, common lambsquarters, redroot pigweed, common ragweed, and giant ragweed are relatively easy to control with very economical rates of 2,4-D. Velvetleaf can be controlled more effectively with 2,4-D than with dicamba. The current reduced rate restrictions for atrazine use are allowing velvetleaf to proliferate in corn, emphasizing the need for continued availability of 2,4-D.

Soybean. The degree of soybean yield reduction is generally proportional to the amount of weed biomass competing with the crop. Yield loss may be minor for just a few weeds but can range to no soybean yield with intense weed infestations. For weeds that begin growing at the same time as the crop, the principle of competition is that for each pound of weeds produced there is a proportional decrease in amount of crop produced (10). However, the ratio is not always 1:1 on a biomass basis.

There has been less research on effect of weeds that begin growing before the crop is planted, but experience indicates that weeds that have a head start on the cropcrop. Yield loss may be minor for just a few weeds but can range to no soybean yield with intense weed infestations. For weeds that begin growing at the same time as the crop, the principle of competition is that for each pound of weeds produced there is a proportional decrease in amount of crop

Some broadleaf weeds that can be a problem for no-till soybean include horseweed, prickly lettuce, dandelion, common lambsquarters, giant ragweed, and common ragweed. Use of 2,4-D before planting can be quite helpful for controlling such weeds in no-till soybean.

For postemergence use in soybean, 2,4-DB can selectively control common cocklebur, annual morningglory, and giant ragweed. Although some other herbicides can give good control of common cocklebur, they are not as effective as 2,4-DB on annual morningglory and giant ragweed, and they are more expensive.

Sorghum. Compared to corn, sorghum grows slowly for the first few weeks after planting, making it more vulnerable to rapidly growing weeds. Only one pigweed per 8 feet of sorghum row can reduce grain yield by 700 lb/A (2). Broadleaf weeds in sorghum include pigweed, common lambsquarters, kochia, common and tall waterhemp, smartweed, velvetleaf, common ragweed, giant ragweed, morningglory species, cocklebur, sicklepod, hemp sesbania, sunflower, and nightshade. Perennial broadleaf weeds such as Canada thistle, field bindweed, common milkweed, and dogbane can be extremely competitive. Some perennial weeds are controlled or suppressed by postemergence applications of 2,4-D.

Peanut. Because many broadleaf weeds grow much taller than peanut, they can have a very dramatic and severe competitive effect and essentially make peanut production impossible. Some of the most troublesome broadleaf weeds in peanut include bristly starbur, common lambsquarters, common ragweed, croton spp., eclipta, Florida beggarweed, hophornbeam copperleaf, morningglory species, pigweed, prickly sida, sicklepod, and spurge species (3). Most of these weeds are controlled or suppressed by postemergence applications of 2,4-DB.

CURRENT WEED CONTROL METHODS

Field corn. Because it occupies so much acreage in the United States, much research and development of herbicides has been directed towards corn. As a result, numerous herbicides are registered alone, or in mixtures, for use in corn. However, in this section only 2,4-D (the only phenoxy herbicide used in corn) will be considered. Some of the other herbicides currently available for use in corn will be mentioned later when alternatives to the phenoxy herbicides are considered.

Currently, 2,4-D is used primarily prior to planting no-till corn or as an early postemergence application in corn. However, some later postemergence applications are made because 2,4-D is more effective on larger weeds than are most other herbicides. Use of 2,4-D as a soil-applied preemergence treatment has been largely replaced by more selective herbicides. Some preharvest treatments are made after the dough to dent stage of corn kernels, primarily for control of perennial broadleaf weeds, but high clearance equipment is needed and is not as readily available as it was formerly. Aerial application of 2,4-D in corn is not common, due largely to risk of movement outside the target area and potential damage to sensitive plants.

The ester formulations of 2,4-D can volatilize after application and then move, and all formulations can move by drifting of spray particles. Considerable precaution is needed with the use of phenoxy herbicides to avoid injury to sensitive plants in the vicinity. Because 2,4-D is not considered very toxic to warm-blooded animals and relatively low rates are used, toxicity to humans and animals has not been a significant concern.

Cultivation between the rows is still an important method of weed control in corn. However, interest in no-till crop production has greatly increased in order to help conserve soil, moisture, fossil fuel, equipment expense, and labor. Thus, the use of 2,4-D prior to planting for control of existing vegetation has become of increasing importance for sustainable agriculture production systems.

Soybean. Soybean, as with corn, has received considerable attention from the chemical industry, and as a result, many herbicides are registered for use in soybean. Some of these will be mentioned when alternatives to the phenoxy herbicides are considered.

Cultivation is still an important method of weed control in soybean, but as with corn, no-till soybean production has become increasingly important. A significant need is filled with 2,4-D as a preplant treatment for no-till soybean production. One of the most popular treatments is about 0.5 lb/A of glyphosate plus 0.5 lb/A 2,4-D low volatile ester for broad-spectrum control of existing vegetation prior to planting. For control of two of the most important weeds in no-till, glyphosate gives better control of horseweed, whereas 2,4-D is better on prickly lettuce. Thus, this herbicide combination has become quite popular.

There is little use of 2,4-DB prior to planting no-till soybean because there is little or no advantage over 2,4-D and it costs more. To broaden the spectrum of control, 2,4-DB has been added to some other postemergence herbicides. However, because of some risk of soybean injury, use of 2,4-DB has declined as more selective herbicides have been introduced.

Sorghum. For control of annual grass weeds in sorghum, the main herbicides are propachlor, alachlor, and metolachlor, all soil-applied. Sorghum has good tolerance to propachlor; however, the herbicide is better adapted to relatively dark soils with a moderate amount of organic matter; whereas sorghum is often grown on the lighter colored soils, which are relatively low in organic matter. Although sorghum has limited tolerance to alachlor and metolachlor, seed treatment with safening agents allow their use in this crop.

Although used primarily for control of annual grass weeds, propachlor can provide relatively good control of pigweed and may be of some help for control of common lambsquarters and smartweed. Alachlor or metolachlor, in addition to controlling annual grass weeds, can control pigweed and may give some control of common lambsquarters, eastern black nightshade, nutsedge, common ragweed, jimsonweed, and smartweed. Although these three herbicides may provide some broadleaf weed control, they are commonly used in combination with a triazine herbicide to improve broadleaf weed control. Or, they may be used preemergence alone and followed by a postemergence treatment with a triazine herbicide to control broadleaf weeds.

Soil-applied herbicides for broadleaf weed control in sorghum are quite limited. Propazine was formerly used and was generally the preferred triazine herbicide for sorghum, especially in southern production areas. However, the major manufacturer decided, in 1988, not to reregister it for economic reasons. In 1993, it was registered by another manufacturer and has been used primarily in Texas and some in New Mexico. Sorghum is more tolerant of propazine than of atrazine and the majority of southern growers prefer propazine (11) while atrazine is preferred in some northern sorghum producing states. Although cyanazine has been registered for use on sorghum, crop tolerance is limited and relatively little is used. Furthermore, cyanazine registration is being phased out of use for all crops by 2002.

Some triazine herbicides may not be used on coarse textured soils low in organic matter or on high pH soils. There are also restrictions to avoid carryover effect on subsequent crops, and this can be accentuated in the drier areas of the Great Plains.

Except for some control of small annual grass weeds, most postemergence herbicides for sorghum are primarily for control of broadleaf weeds. Postemergence herbicides for sorghum include atrazine, bromoxynil, bromoxynil plus atrazine, bentazon plus atrazine, dicamba, dicamba plus atrazine, and 2,4-D. These postemergence treatments are used as for corn; however, in general, sorghum is less tolerant than corn and timing is more critical. For example, it is preferable to apply 2,4-D to sorghum when it is 4 to 12 inches tall; after 8 inches, "drop nozzles" should be used. Glyphosate or paraquat can be used for "burndown" of weeds prior to planting no-till sorghum and glyphosate can be used as a non-selective, spot treatment prior to sorghum heading.

Peanut. For weed control in peanut, tillage is commonly used at the beginning of the season, supplemented by use of herbicides for control of grass weeds and by some row cultivation. The dinitroaniline herbicides, pendimethalin and ethalfluralin, are incorporated into the soil for control of annual grass weeds, and they also control a few small-seeded broadleaf weeds such as pigweed and common lambsquarters. Vernolate has also been used in a similar manner. Where Texas panicum is not a problem, metolachlor is sometimes used. Some sethoxydim and fenoxaprop is used postemergence for annual grass control. Yellow nutsedge is controlled with soil-applied metolachlor, vernolate, or imazethapyr or postemergence applications of bentazon. For purple nutsedge control, imazethapyr and vernolate are used. For broadleaf weed control, 2,4-DB applied postemergence has been very popular, being used on over 80% of the peanut acreage and sometimes applied more than once. It can be particularly helpful early to mid-season for control of common cocklebur and sicklepod and it can also control such weeds as annual species of morningglory, common lambsquarters, and ragweed. A significant amount of bentazon is also used postemergence, but at higher cost. Bentazon is often used in combination with acifluorfen to improve control of morningglory species, ragweed, croton, wild radish, and copperleaf. However, crop injury is an occasional concern with acifluorfen. Imazethapyr is a fairly recent introduction used for controlling several important broadleaf weeds and nutsedge, but rotational restrictions impose some limitations. Partly because of cost, imazethapyr use has been limited. Particularly in the southeast, paraquat has been used extensively for early season weed control, although slight to moderate peanut injury typically results (3).

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COST OF CONTROL METHODS

Field corn. The two main formulations of 2,4-D used for corn are the low volatile esters such as butoxyethyl ester and the amines such as the dimethylamine salt. The rate of application varies with formulation and also with weed species, time of application, growing conditions, and different labels. A low volatile ester at 0.25 lb/A might be used postemergence at a cost, for herbicide only, of about $1/A. Because amines are less active than the esters, they are usually used at about 0.5 lb/A postemergence for corn at a cost of about $2/A. Cost of preharvest treatment would be similar. A typical preplant application for no-till corn would be about 0.5 lb/A of 2,4-D ester for a cost of about $2/A. Compared with most other herbicides, 2,4-D is relatively inexpensive.

Soybean. When used in no-till soybean production, the low-volatile ester of 2,4-D at a common rate of about 0.5 lb/A, costs about $2/A. With glyphosate at 0.5 lb/A, the cost is about $5/A, but for some small weeds, glyphosate might be reduced to about 0.38 lb/A or about $4/A. Thus, a relatively common treatment prior to planting no-till soybean costs about $6 to $7/A for the glyphosate plus 2,4-D combination.

The cost of 0.2 lb/A of 2,4-DB, for postemergence use in soybean, is about $3.60/A. However, 0.03 lb/A has been a relatively common rate for mixing with other herbicides for postemergence treatments. This rate would add only about 50 to 60 cents per acre for improved control of weeds such as annual morningglory.

Sorghum. Most of the preemergence treatments with propachlor, alachlor, or metolachlor in combination with atrazine cost about $15 to $20/A. The postemergence herbicides that are premixed with atrazine range from about $6 to $10/A. Cost of 2,4-D is about $1/A for low volatile ester at 0.25 lb/A and $2/A for amine at 0.5 lb/A. Thus, 2,4-D is by far the most cost effective treatment.

Rotary hoeing and row cultivation are also options and cost could be estimated at about $4/A for each trip over the field. Rotary hoeing would be used once or possibly twice. Most sorghum growers cultivate twice but some may cultivate three times (11). Because sorghum is a low value crop compared with corn, low cost of weed control is quite important.

Peanut. Cost of 2,4-DB for postemergence use in peanut is about $7/A at the high rate of 0.38 lb/A or $4.50/A for the 0.23 lb/A rate, which is quite sufficient for controlling common cocklebur. A 1 lb/A rate of bentazon would be about $17/A or $8.50 for the lower 0.5 lb/A rate. Acifluorfen at 0.25 lb/A would be about $7/A and imazethapyr at 0.063 lb/A would be about $20/A.

IMPACT OF THE LOSS OF 2,4-D OR ALL PHENOXY HERBICIDES

Field corn. The loss of 2,4-D would have a significant impact on corn production. Because 2,4-D is the only phenoxy herbicide currently used in corn, loss of other phenoxy herbicides would have no effect.

Although not used as extensively as in earlier years, 2,4-D still serves several important needs for corn growers at a very reasonable cost. With a very significant increase in no-till corn production, the use of 2,4-D has become increasingly important for control of existing vegetation prior to planting. Other herbicides for similar use include paraquat and glyphosate. However, 2,4-D has some advantages over paraquat or glyphosate for control of certain weed species important in no-till production. The use of 2,4-D gives better control than glyphosate of prickly lettuce, hairy vetch, and alfalfa. Thus, a combination of 2,4-D plus glyphosate is commonly used. The 2,4-D gives better control than paraquat of horseweed, prickly lettuce, common lambsquarters, common and giant ragweed, hairy vetch, and alfalfa. In addition, for the applicator, 2,4-D is safer to use than paraquat. For control of perennial weeds, which increase with no-till, 2,4-D has a significant advantage over paraquat because 2,4-D translocates into roots whereas paraquat does not. Although the triazines can give some "burndown" for no-till preplant applications, they are not as effective as 2,4-D for controlling perennial weeds. Postemergence use of 2,4-D in corn has diminished from over 50% of the corn acreage treated down to about 11% of the corn acreage now being treated (Table 1). However, postemergence broadleaf control remains a very important use in corn. The effectiveness of soil-applied preemergence herbicides is quite dependent on rainfall to enhance absorption by weeds, which does not always occur in a timely manner. Thus, a backup postemergence treatment is often needed, and 2,4-D remains the most economical treatment in this category and one of the most popular.

Our survey indicated that if 2,4-D were no longer available for weed control in corn production, growers would use dicamba on an estimated 33% of the acres currently treated with 2,4-D, atrazine on 26%, and cyanazine on 16%, while bentazon, bromon an estimated 33% of the acres currently treated with 2,4-D, atrazine on 26%, and cyanazine on 16%, while bentazon, bromoxynil, and glyphosate would each be used on 7% of those acres. A total of 3.4 million pounds of alternative herbicides at a cost of $72 million might replace the 3.3 million pounds of 2,4-D currently being used at a cost of $10.6 million. Survey respondents suggested that non-chemical weed control methods, including preplant tillage and cultivation, might be used principally in Georgia, Alabama, Massachusetts, and New Hampshire. Total estimated national expendi

Based on the survey, yield loss estimates were significant for a number of states. In the West, losses of 25% were predicted for Washington corn without 2,4-D, while in Montana production loss was estimated at 10%. In the South, growers could experience losses of 10% in Georgia and Louisiana, and 5% in Mississippi, Alabama, and South Carolina. A 20% loss was predicted in Delaware. In the corn belt, Illinois growers could experience a 3% decrease in yield while no yield loss is expected in Iowa and Indiana. The overall weighted average yield loss was estimated to be 1% (Table 2).

With the AGSIM model, there was a predicted farm-level corn-price increase of 1.9%, with a 2,4-D ban. The resulting increase in consumer costs would be about $194 million, and the increase in production cost would approach $52 million, or $6.55 per acre on acreage currently being treated with 2,4-D. A revenue increase of $2.57/A was predicted for acres not being treated with 2,4-D because of an increased price for corn if 2,4-D was banned. The net societal effect was estimated to be an annual loss of $246 million for the loss of 2,4-D (the only phenoxy herbicide involved) in corn production (Figure 5).

Soybean. Use of 2,4-D prior to planting no-till soybean has had a very significant impact on the adoption and success of no-till soybean production. In addition to helping farmers conserve soil to meet conservation compliance, this technology has reduced the amount of tillage with a concomitant savings in labor, equipment expense, and fossil fuel. Loss of 2,4-D for no-till soybean production would have a significant adverse effect on the benefits currently being achieved with no-till. If 2,4-D were no longer registered for preplant application for no-till soybean, glyphosate alone rather than glyphosate plus 2,4-D would be a possibility, but the weed control spectrum would be narrower and higher rates of glyphosate would likely be needed at higher cost.

Paraquat is sometimes used with 2,4-D for preplant application for no-till soybean, but used alone, paraquat is not as good as 2,4-D on some weed species such as horseweed, prickly lettuce, giant ragweed, and common lambsquarters. Paraquat does not translocate to roots as 2,4-D does, and thus it is not as good for perennial weed control.

Our survey indicated that a ban of 2,4-D could cause more extensive use of 2,4-DB for soybean, with 2,4-DB replacing 2,4-D on 32% of the acres. However, 53% of the 2,4-D treated acres would have glyphosate used as a substitute, and paraquat would likely be used on another 11% of those acres. The total amount of substitute chemical materials that could be applied was estimated as 1.1 million pounds at a total expenditure of $20.1 million to replace the 917,000 pounds of 2,4-D with an estimated cost of $2.9 million.

The situation changes somewhat if one assumes the loss of all phenoxy herbicides. Under those circumstances, glyphosate would remain the alternative herbicide of choice, being used on 54% of those acres currently treated with phenoxy herbicides; 12% of those acres would be treated with paraquat, 8% with acifluorfen, 11% with bentazon; and 10% of those acres would receive applications of other herbicides. With the loss of all phenoxy herbicides, 1.2 million pounds of alternatives were estimated to be used, at a total cost of $26.9 million. Preplant tillage was the most popular non-chemical weed control alternative mentioned to replace phenoxy herbicides on up to 80% of treated acres in North Dakota, 33% in North Carolina, 40% in Iowa, and 25% in Illinois and Indiana. Total estimated cost for non-chemical weed control methods was $2.1 million.

Yield loss estimates generally varied between 1% and 5% for the loss of 2,4-D scenario. If, however, all phenoxy herbicides were lost, yield loss estimates increase considerably. An 8% yield loss was forecast for Indiana, 15% in Georgia, 10% in Kentucky and Tennessee, 7% in Arkansas, and 30% in Delaware. Regionally, the Northeast was estimated to experience the largest decrease in yield at 6.3% while the corn belt may see yields drop by 1.5%. States in the Appalachian region could experience a 3% decrease in yield. The weighted average yield effect nationally for a loss of all phenoxys was a decrease of 1.2%.

With the AGSIM model, assuming the loss of all phenoxy herbicides used in soybean production (e.g. 2,4-D and 2,4-DB), there was a predicted farm-level soybean-price increase of 1.6%. The resulting loss in consumer surplus was estimated to be $172 million and the increase in production cost could approach $20.2 million or $6.34/A on acres formerly treated with any phenoxy herbicide. Net farm revenue could increase by $17.6 million because of the farm gate increase associated with the estimated yield loss. This effect is much more significant should all phenoxy herbicides be lost than if only 2,4-D is banned. The annual net societal loss of banning 2,4-D was estimated to be $34.6 million and $155 million from the banning of all phenoxy herbicides for soybean (Figure 5).

Sorghum. Growers use 2,4-D on about 11% of the sorghum acreage of 11.4 million acres or 1.27 million acres (Table 1). If 2,4-D were not available, growers would likely turn to atrazine as the major means of controlling broadleaf weeds. Use of atrazine preemergence might be increased, and for postemergence use, combinations with atrazine plus bromoxynil, dicamba, or bentazon could be used. One of the primary impacts of losing 2,4-D would be the higher cost of weed control for growers. With 2,4-D at about $1 to $2/A, it is lower in cost than any of the other postemergence options. Dicamba alone would be about $4.50/A at the 0.25 lb/A rate. Other postemergence options range from about $6 to nearly $15/A.

For non-chemical control, farmers would do more rotary hoeing and cultivating. However, depending on weather, rotary hoeing is not always possible and row-cultivation is generally not as effective as herbicides for controlling weeds in the crop row. In the dry areas of the Great Plains where sorghum is a major crop, extra cultivation would result in soil moisture loss and yield reduction as compared to using herbicides for weed control.

For no-till sorghum, 2,4-D applied preplant has been very helpful for cost-effective weed control. A combination of 2,4-D and dicamba or 2,4-D and glyphosate is very helpful, and sometimes almost essential, for control of weeds associated with no-till, as well as for control of some cover crops. These herbicides are very beneficial for control of perennial weeds and there is usually no other alternative that is as cost effective. Thus, loss of 2,4-D could have a very significant impact on use of no-till sorghum production which conserves soil and water resources. Water resources can be quite critical in some of the relatively dry areas where sorghum is produced. Non-chemical control with more tillage and cultivation would also require more fossil fuel and equipment, thus consuming non-renewable energy resources.

Our survey indicated that banning 2,4-D could cause sorghum growers to substitute atrazine on 68% of those acres formerly treated with 2,4-D, bentazon on 12%, bromoxynil on 11%, and dicamba on 8%. A total of 467,000 pounds of alternative herbicides would be applied at an estimated cost of $4.2 million. Crop cultivation was the most popular alternative non-chemical weed control reported and would be used on 40% of those acres formerly treated with 2,4-D in Alabama, on 30% in Mississippi, on 20% in Georgia, and on 5% in Nebraska. Total estimated cost of cultivation to replace 2,4-D treatments was $123,000.

Sorghum yield loss estimates were significant for a number of states. The Tennessee respondent estimated a 25% loss in yield without 2,4-D. It was 15% for Georgia, 10% for Alabama, Colorado, and Louisiana, and 7% for South Carolina. Losses of 5%, or less, were predicted for Illinois, Kentucky, and South Dakota. The weighted average sorghum yield loss with the loss of 2,4-D was estimated as 2.4% (Table 2).

The AGSIM model predicted an increase in commodity price of 0.7% with the loss of 2,4-D. The resulting increase in consumer costs could be $6.5 million, and the increase in sorghum production costs could approach $6.3 million or $4.98/A on those acres currently being treated with 2,4-D. Net revenue on treated acreage was predicted to decline by $24.2 million or $6.54/A on acres currently being treated with 2,4-D, and revenue on acres not now being treated with 2,4-D would increase an estimated $0.58 per acre. The net societal effect is an estimated loss of $30.7 million from a ban on 2,4-D, the only phenoxy herbicide used in sorghum production (Figure 5).

Peanut. If 2,4-DB (the only phenoxy herbicide used in peanut production) were lost, there would likely be a significant increase in use of bentazon, some increase in use of acifluorfen, partly to broaden the spectrum of weed control, and some increase in use of imazethapyr, where appropriate, by those willing to pay the higher cost. A slight increase in use of paraquat might also occur in some areas of peanut production.

Weeds such as common cocklebur and sicklepod can be quite serious in peanut production areas and 2,4-DB is quite helpful for their control. Such weeds could proliferate and seriously reduce peanut production if 2,4-DB were not available. Currently there is no substitute for 2,4-DB for mid-season control of sicklepod.

Our survey indicated that if 2,4-DB were banned for use in peanut production, growers would substitute bentazon on 70% of acres formerly treated with 2,4-DB, 22% of those acres would receive acifluorfen, 4% would receive paraquat, and the remaining 4% would receive imazethapyr. A total of 339,000 pounds of alternative chemical materials would be used to replace 2,4-DB at an estimated cost of $11.6 million. Cultivation was predicted to be the most popular non-chemical weed control alternative. Respondents in Virginia and North Carolina estimated 40% of acres formerly treated with 2,4-DB would be cultivated for weed control; 30% of those acres in Georgia, 20% in Alabama, and 15% in Florida. Total estimated expenditure for non-chemical weed control methods was $1.88 million.

Yield loss estimates with a 2,4-DB ban were significant for a number of major peanut producing states. In Georgia, a 20% yield reduction was predicted on 100% of peanut acres because 2,4-DB is used on the entire peanut crop. In Florida, a 20% yield loss was estimated on the 90% of the peanut acres formerly treated with 2,4-DB, and 15% yield loss in Alabama, where 80% of the crop was formerly treated with 2,4-DB. The weighted average yield loss estimate for all peanut growing regions in aggregate was 13.3% (Table 2).

Using the AGSIM model, a farm level price increase for peanut of 1.5% was predicted with the loss of 2,4-DB. The resulting loss in consumer surplus was estimated at $15.9 million and the increase in production cost would be about $4.3 million or $2.86/A on those acres currently treated with 2,4 DB. Net revenue loss could approach $123 million or $67.19/A on acres currently treated with 2,4-DB. A net revenue increase of $9.17/A would be incurred by non-users of 2,4-DB. Peanut producers who currently use 2,4-DB in the Southeast could see revenue fall by $138/A, in Appalachia by $47/A, and in the Southern Plains by $25/A. Current non-users of phenoxy herbicides could see revenues increase in the Southeast by $15.13/A and in Appalachia by $2.80/A. The net societal effect, if 2,4-DB (the only phenoxy herbicide involved) were banned in peanut production, would be an annual loss of $139 million (Figure 5).

WEED CONTROL ALTERNATIVES IF EITHER 2,4-D OR ALL PHENOXY HERBICIDES WERE LOST

Field corn. Postemergence herbicide alternatives to 2,4-D (the only phenoxy herbicide involved) for control of broadleaf weeds in corn include atrazine, cyanazine, dicamba, bromoxynil, bentazon, pyridate, and imazethapyr. There are also premixed combinations such as dicamba plus atrazine, bromoxynil plus atrazine, and bentazon plus atrazine. Atrazine and cyanazine are used postemergence in corn when weeds are relatively small. However, with atrazine, rate limitations and residual considerations limit postemergence use, and cyanazine presumably is being phased out. For postemergence use, atrazine is now commonly used at a reduced rate in combination with other herbicides such as dicamba, bentazon, and bromoxynil; and this has increased control cost as compared to a higher rate of atrazine alone.

Dicamba is used in a somewhat similar manner as 2,4-D. However, dicamba is more effective than 2,4-D on smartweed, but it is less effective on velvetleaf and dandelion (an important weed in no-till). Dicamba also presents a greater risk than 2,4-D for movement outside the target area. One of the most prevalent weeds in much of the corn belt is velvetleaf. With current restrictions on atrazine rates, its allowable preemergence rates are often not high enough for adequate control of velvetleaf. Although dicamba is available, it is not as good as 2,4-D for velvetleaf control and there has been little else to equal the effectiveness and economy of 2,4-D for the control of this major weed species. Two new herbicides, flumiclorac-pentyl and CGA-248757, are quite effective on velvetleaf, but their costs would be significantly higher.

Although bromoxynil or bentazon can control relatively small weeds, their activity is primarily by contact action, whereas 2,4-D, being translocated, is more effective on larger weeds and even some perennial weeds. Pyridate is also intended for relatively small weeds and, being recently introduced for corn, has not yet been widely used. Imazethapyr is primarily used for soybean but may be used on imidazolinone-resistant or tolerant corn, which means some increase in seed cost. Continuous use of imazethapyr for both corn and soybean could hasten the development of herbicide-resistant weeds.

Primisulfuron is a relatively new introduction that gives good control of shattercane and johnsongrass, but its spectrum of broadleaf weed control is somewhat limited. A combination of primisulfuron plus prosulfuron (CGA-152005) appears promising but would likely be significantly higher in cost than 2,4-D. Clopyralid is a relatively new postemergence herbicide for corn used at 0.094 to 0.25 lb/A at a cost of about $14 to $38/A. It is effective on some special weeds such as Canada thistle, Jerusalem artichoke, common ragweed, common cocklebur, jimsonweed, and common sunflower. At this cost, it will likely be used primarily for limited infestations of difficult-to-control weeds and does not appear to be a good candidate for controlling such weeds as common cocklebur and common ragweed, which can be easily controlled at much lower cost with 2,4-D.

Some relatively new compounds, such as prosulfuron, halosulfuron, flumetsulam, flumiclorac-pentyl, and CGA-248757 may find a place for broadleaf weed control in corn, but spectrum of control may be rather limited for some and cost will likely be much higher than for 2,4-D. Such factors as degree of crop tolerance and degree of herbicide residual will also be important considerations.

Linuron, paraquat, and ametryn may be possible alternatives for directed postemergence in corn, but there is very little use of these herbicides, partly because very few farmers in the corn belt have directed spray equipment. Furthermore, the need for these herbicides would be more for control of grass weeds rather than broadleaf weeds.

Soybean. The herbicide 2,4-DB might be a possible alternative for 2,4-D for use in no-till soybean production, but at labeled rates the spectrum of control is not as broad as with 2,4-D and cost would be significantly higher. Also, 2,4-DB would not be available if all phenoxy herbicides were banned. Dicamba is a possible alternative to 2,4-D for corn, but the soil residual activity of dicamba applied preplant in the spring would be too great for use before soybean planting because soybean is very sensitive to dicamba. Chlorimuron plus metribuzin can provide both "burndown" and residual activity for no-till soybean production, but soil residual activity can be a problem for corn production the following year, particularly on high pH soils. Imazethapyr can have both preemergence and postemergence activity on some weeds, but does not give good control of horseweed and prickly lettuce, two important weeds associated with no-till soybean production.

Alternatives to the phenoxy herbicides for preplant weed control for no-till soybean production include glyphosate, paraquat, chlorimuron plus metribuzin, and imazethapyr. However, cost would be significantly greater than with the phenoxy herbicides, spectrum of weed control genchlorimuron plus metribuzin, and imazethapyr. However, cost would be significantly greater th

Sorghum. The only phenoxy herbicide currently used for weed control in sorghum is 2,4-D. Atrazine can control many of the same weeds as 2,4-D, but it has less flexibility than 2,4-D for time of postemergence application. In the relatively dry areas, where much of the sorghum is produced, there can be limitations on atrazine use because of risk of carryover effect on subsequent crops. There is little or no concern of soil residue carryover with 2,4-D. Dicamba would be one alternative to 2,4-D for sorghum, however some problems with movement outside the target area can be more significant with dicamba than with 2,4-D.

Postemergence combinations with reduced rates of atrazine plus bromoxynil, bentazon, or dicamba have a similar spectrum of weed control as 2,4-D and may sometimes have a little crop safety advantage. However, they are significantly higher in cost. Cultivation might be an alternative, but with the large acreages being farmed, most growers would prefer less, not more, cultivation.

Peanut. If 2,4-DB (the only phenoxy herbicide currently used in peanut production) were banned, bentazon would be the major alternative herbicide. Bentazon was projected to be used on 70% of those acres currently being treated with 2,4-DB, but at a greater cost.

Cultivation would increase if 2,4-DB were lost, but cost of peanut production would increase. Growers are striving to reduce rather than increase cultivation. Reducing cultivation in peanut production is desirable because, when cultivating, special care must be taken to avoid excessive soil movement and coverage of the plants any time during the season. "Dirting" the crop or mechanical injury may adversely affect flowering and pegging and may encourage soil-borne disease (3, 4, 9, 14).

Pegging refers to the process after pollination when the gynophore or "peg" elongates and pushes the ovary into the soil where the peanut pod develops.

COMPELLING REASONS THAT SHOULD PREVENT THE LOSS OF THE PHENOXY HERBICIDES

Field corn. Some of the reasons listed here under field corn would apply similarly for soybean, sorghum, and peanut.

1. Application of 2,4-D provides the lowest cost weed control. At a cost of about $1 to $1.50/A for 8 million acres, the national expenditure is $8 to $12 million. At a cost of about $8 to $19 more per acre for alternatives, this would mean an added expenditure of about $64 to $152 million for United States corn farmers each year.

2. Although a very small percentage (estimated at 1 to 2%) of the corn treated may have significant injury from 2,4-D, it is still one of the most selective herbicides.

3. The timing of application for 2,4-D is quite broad from before emergence to about tassel stage and resuming at dough stage.

4. Because it is translocated to weed roots, 2,4-D provides control of perennial as well as annual weeds to a greater extent than many other herbicides.

5. Use of 2,4-D prior to planting no-till corn has helped greatly to assure success of no-till crop production, resulting in very significant conservation of soil, water, fuel, equipment, and labor resources. With 2,4-D as a key component, no-till production is maintaining or increasing corn yields, while leaving more land undisturbed for wildlife. No-till also allows grain lost during harvest to remain on the soil surface where it is readily available as food for wildlife.

6. Because persistence of 2,4-D in the environment is relatively short, there is little concern about residual effect on crops grown in rotation with corn or groundwater contamination.

7. After half a century of use, there is still relatively little concern about weeds developing resistance to 2,4-D. However, weed resistance is a significant concern with many of the more recently introduced herbicides.

8. Many species of broadleaf weeds are controlled by 2,4-D.

9. After half a century of use, 2,4-D has been shown to have relatively low risk from an animal or human toxicology viewpoint.

10. Use of 2,4-D is quite beneficial for controlling weeds such as common ragweed that cause allergies to humans. It is also beneficial for control of many weeds poisonous to livestock and humans.

Soybean.

1. Use of 2,4-D for preplant application for no-till soybean production has been a major factor in the success and rapid adoption of this production method, because it conserves both soil and energy resources.

2. The use of 2,4-D for preplant application for no-till soybean production provides more economical and broader spectrum control of broadleaf weeds than any other production alternative currently

available.

3. Other than glyphosate, 2,4-D is about the only translocated herbicide available to control broadleaf perennial weeds prior to planting no-till soybean. The combination of 2,4-D and glyphosate provides more economical and effective broad spectrum weed control than glyphosate alone. Currently, there are few other alternative herbicides for broad spectrum weed control prior to planting no-till soybean production fields.

Sorghum.

1. Although some care is needed with use of 2,4-D to avoid injury to sorghum and to reduce potential for movement outside the target area, 2,4-D is still one of the main herbicides for sorghum.

2. As with other crops, 2,4-D provides one of the keys to success for no-till, providing control of many major weeds associated with no-till sorghum production. Rather than being replaced by dicamba or glyphosate, 2,4-D is needed in combination with these compounds to economically broaden the spectrum of weed control in no-till production.

3. Significant cost savings are made possible by 2,4-D as the lowest cost herbicide available for sorghum. Since sorghum is not a high value crop, limiting weed control costs are very important to profitable production.

Peanut.

1. The only phenoxy herbicide used in peanut production, 2,4-DB, is used on about 83% of all peanut acres in the United States.

2. For peanut, 2,4-DB provides a relatively low cost postemergence treatment for control of broadleaf weeds, and it controls many of the weeds commonly found in the peanut production areas.

3. Some alternative herbicides would cost three to five times more than 2,4-DB for controlling weeds in peanut production.

4. One of the few herbicides for control of sicklepod in peanut is 2,4-DB, and it is also very effective on common cocklebur.

5. Because of the rather limited acreage of peanut, herbicide manufacturers are often reluctant to invest in research, development, and registration of herbicides for this high value, low acreage, edible crop. So highly effective and economical alternatives for 2,4-DB in peanut production are not likely to be available soon.

WEED RESISTANCE MANAGEMENT

Although 2,4-D has been used for half a century, LeBaron and Gressel indicate that there has been very little concern about development of weed resistance with 2,4-D (8). Regehr and Morishita (13) attribute this to 2,4-D being a hormonal-type herbicide that interferes simultaneously with many growth processes, whereas some other herbicides hadevelopment of weed resistance with 2,4-D (8). Regehr and Morishita (13) attribute this to 2,4-D being a hormonal-type herbicide that interferes simultaneously with many growth processes, whereas some other herbicides have primarily a single site of action. They also indicate that because 2,4-D is degraded rather rapidly, it exerts only moderate, temporary selective pressure on weeds. Although true resistance has not been much of a problem with 2,4-D, various species, and biotypes within a species, can vary considerably in tolerance to 2,4-D. Widholm (16) indicates that cell culture research has been done attempting to develop crop cultivars with increased tolerance to 2,4-D, but industry representatives have not expressed much interest in this research because of the low profit potential with the sale of 2,4-D. However, breeding

Development of weed resistance has become a significant concern with some other herbicides such as the triazines, sulfonylureas, and the imidazolinones. Use of 2,4-D can be quite beneficial for programs to help manage weeds that have developed resistance to some of these other herbicides. Where the imidazolinones are used for no-till, 2,4-D is considered almost essential to provide control of horseweed and prickly lettuce. Thus, 2,4-D can broaden the spectrum of control as well as help in managing weed resistance. Long-term use of 2,4-DB in peanut production in conjunction with standard crop rotations has resulted in few weed resistance problems.

FUTURE WEED MANAGEMENT OPTIONS

Field corn. If 2,4-D continues to be available, use could increase slightly. Use for postemergence control of broadleaf weeds in corn tended to stabilize somewhat in the 1980's and early 1990's. However, with recent restrictions on triazine rates, 2,4-D has become more important, especially for control of such important weeds as velvetleaf. The development of weed resistance with some other herbicides could also contribute to an increasing need for 2,4-D. Also, the rapid increase in no-till production has caused an increase in use of 2,4-D for control of existing weeds or cover crops, such as alfalfa, prior to planting corn.

Soybean. Interest in production of no-till soybean has intensified, and acreage of no-till soybean may continue to increase. Control of existing weeds or a cover crop prior to planting is the first essential step for no-till. The majority of the United States no-till acreage is treated with 2,4-D. A glyphosate plus 2,4-D combination is frequently used, because it provides effective and economical broad spectrum control with few problems. There currently is no other herbicide with the equivalent benefits of 2,4-D for use in no-till production.

Use of 2,4-DB, although registered for similar use as 2,4-D preplant for no-till soybean, will not likely increase because of its higher cost and more limited spectrum of weed control. Use of 2,4-DB postemergence in soybean will not likely increase because of the availability of several alternatives with better soybean selectively and broader spectrum of weed control. Addition of 2,4-DB to some other herbicide mixtures at a cost of only about 50 cents per acre may continue in some geographic areas, but because of the introduction of several newer herbicides, this practice is not as common as earlier.

One recent technological development has been glyphosate tolerant soybean. Research is in progress to delineate rates, timing, and number of applications of glyphosate needed for soybean production. Although there is considerable interest in this concept, it will not eliminate the need for 2,4-D added to glyphosate to broaden the control spectrum for preplant weed control in no-till soybean. Sulfosate may soon become available for use in a very similar manner and with very similar results as with glyphosate for no-till soybean. Although this could mean keener competition for glyphosate, it would have little impact on the need for 2,4-D.

Sorghum. In addition to glyphosate, the herbicides sulfosate and glufosinate may become more available in the future for use in sorghum production, but this should have little impact on the need for 2,4-D. Two new herbicides for broadleaf weed control in corn are prosulfuron and halosulfuron. Because they have little effect on grass, they may offer some potential for broadleaf weed control in sorghum if the manufacturers believe that expanded registration is economically feasible. However, they are acetolactate synthase (ALS) inhibitors with a mode-of-action similar to many other herbicides, and monitoring for weed resistance potential would be essential if prosulfuron or halosulfuron became commonly used. The possibility of adverse additive effects from excessive use of ALS inhibitors in a crop rotation may also be a significant consideration. Cost of any new herbicides would likely be significantly higher than for 2,4-D.

Although development of herbicide tolerant sorghum is a possibility, much less attention is being given to sorghum than to major crops such as corn and soybean. There has been relatively little development of practical new techniques for mechanical control of weeds. Cultural practices such as narrow rows and relatively high plant populations have already been adopted to aid in weed control for sorghum. Compared to corn and soybean, the seedlings of sorghum are smaller and mechanical control must be used more carefully to avoid damage to the crop.

Peanut. Pyridate is a possible new herbicide for broadleaf weed control in peanut production, but availability is uncertain and the per-acre cost estimates are about two to three times the cost of 2,4-DB. There may also be potential for a new imidazolinone, imazameth (AC 263,222). There appears to be relatively little else on the horizon to offer significant new developments in weed control for peanut in the near future. Finding a herbicide to control broadleaf weeds in a broadleaf crop is not easy. Herbicide manufacturers have limited interest for investing in discovery, development, and registration for a crop such as peanut with limited acreage. Also there appears to be little attention given to developing peanut lines with genetic tolerance or resistance to existing herbicides. Likewise, little interest has been expressed in development of new methods of non-chemical control. Thus, the widespread use of 2,4-DB on peanut acreage appears to be a key factor for continued successful peanut production.

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- Table of Contents **Table 1**. Yearly production, price, and phenoxy herbicide use for field corn, soybean, sorghum, and peanut production in the United States during 1992.

				Phenoxy herbicide use[b]				
>	Crop and herbicide	Acres[a]	Production and yield units	Price	Acres treated		Pounds	Rate
	(000)	(000)	$/unit	(000)	%	(000)	lb/A	
Field corn	73,823	9,764,000 bu	2.02					
2,4-D				7,900	10.7	3,307	0.42	
Soybean	59,200	1,945,059 bu	5.70					
2,4-D				1,771	3.0	917	0.52	
2,4-DB				1,407	2.4	365	0.26	
Sorghum	11,399	589,404 bu	1.70					
2,4-D				1,270	11.1	484	0.38	
Peanut	1,848	4,173,112 lb	0.26					
2,4-DB				1,530	82.8	567	0.37	

[a] Average for years 1989 to 1991.

[b] Based on survey conducted in 1993 for 1992 use.

Table 2. Estimated changes in production and in cost of production of field corn, soybean, sorghum, and peanut in the United States during 1992 if 2,4-D or all phenoxy herbicides were banned.

	Assuming loss of 2,4-D				Assuming loss of all phenoxy herbicides			
	Loss of production				Loss of production			
Crop	Quantity and yield units	Proportion of total	Increased cost per treated acre [a]	Total cost change	Quantity and yield units	Proportion of total	Increased cost per treated acre [b]	Total cost change
	(000)	%	$	$(000)	(000)	%	$	$(000)
Field corn[c]	92,000 bu	0.9	6.55	51,738	92,000 bu	0.9	6.55	51,738
Soybean [d]	4,085 bu	0.2	6.34	11,224	23,341 bu	1.2	6.34	20,204
Sorghum [c]	4,146 bu	2.4	4.98	6,300	4,146 bu	2.4	4.98	6,300
Peanut[e]	0	0.0	0.00	0	504,947 lb	13.3	2.86	4,300

[a] Refers to acres estimated to have been previously treated with 2,4-D.

[b] Refers to acres estimated to have been previously treated with any phenoxy herbicide.

[c] Only phenoxy herbicide involved was 2,4-D.

[d]

[d] Both 2,4-D and 2,4-DB.
[e] Only 2,4-DB.

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Figure 1. Most 2,4-D for corn is applied postemergence at very low cost. (Photograph from the author).

Figure 2. The moldboard plow has been largely replaced by the use of herbicides such as 2,4-D that allow reduced tillage or no-till. This has meant considerable savings in fossil fuel, equipment, time, and soil. (Photograph from the author).

Figure 3. Soon after spraying with 2,4-D, broadleaf weeds wilt and die. This is particularly helpful for control of weeds in the crop row that are out of reach for the row cultivator. (Photograph from the author).

Figure 4. Weeds compete with crops to reduce both yield and quality quite significantly. Use of 2,4-D for corn has allowed very effective and economical control of weeds like common cocklebur in corn. Similarly, 2,4-DB can give good control of weeds such as common cocklebur in soybean, including some biotypes that are resistant to some of the newer herbicides with more specific sites of action. (Photograph from the author).

Figure 5. Estimated 1992 net societal loss (production plus consumer costs) for field corn, soybean, peanut, and sorghum of $570,700,000 if all phenoxy herbicides were banned in the United States.

Chapter 7

Use of Phenoxy Herbicides in Turfgrass in the United States

CLYDE L. ELMORE[1]

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Abstract. Turfgrass is a multi-billion dollar commodity in the United States, and it affects the health and well-being of most Americans. Broadleaf weeds can be found in all turfgrass areas, including parks, recreation sites, golf courses, church yards, school yards, cemeteries, and home lawns. Many weeds in turfgrass are controlled by management practices such as mowing, fertilizing, and irrigating; but the primary method of broadleaf weed control in turfgrass is with herbicides, principally phenoxy herbicides. Some broadleaf weeds in turfgrass are not controlled by alternative herbicides.

From a survey of turfgrass specialists, it was estimated that there were 23 million acres of turfgrass during 1992 in the United States, of which 18% was treated with 2,4-D. Other phenoxy herbicides, MCPA, mecoprop, and dichlorprop, are often used in combination with 2,4-D or with non-phenoxy herbicides to reduce rates and increase the spectrum of broadleaf weed control. The principle broadleaf weeds in turfgrass are dandelion, buckhorn plantain, and broadleaf plantain. These weeds are controlled well with 2,4-D, but not as well with other phenoxy or non-phenoxy herbicides.

Survey respondents estimated that 2.8 million pounds of 2,4-D was used annually in the United States at a cost of $28.1 million. Application cost was estimated to be $103.5 million annually. Use of all phenoxy herbicides was 5.2 million pounds at a cost of $64.2 million and an application cost of $190 million. If 2,4-D were banned, alternative herbicides and application costs would total $364 million to replace 2,4-D during 1992. Therefore, the net societal loss of a 2,4-D cancellation would be the difference in application and herbicide cost of $232 million (Table 5).

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Other impacts would be a decrease in broadleaf weed control and a shift of turfgrass service business activities away from pesticide application. No single herbicide, combination of herbicides, or cultural methods would control many of the major broadleaf weeds in turfgrass as well as would 2,4-D.

If all phenoxy herbicides were banned, there would be a dramatic reduction of broadleaf weed control. This would be especially apparent in warm-season turfgrass species in southern United States. There would be less effective alternatives to phenoxy herbicides in cool-season turfgrasses, but there would be no alternative broadleaf herbicide that is safe to use on warm- season turfgrasses to control dandelion. The alternatives, triclopyr or clopyralid, could cause as much as 60% damage to fine bermudagrass. Also, any alternative herbicide would pose a greater injury risk to trees and shrubs than would the phenoxy herbicides.

If all phenoxy herbicides were banned, there would be an estimated increase of 1.6%, or $3.1 million annually, in application costs of alternative herbicides, and an increase of 64% or $107 million in herbicide cost. Because herbicides would not be available on some turfgrass, there would be an estimated increase of $263 million annually to culturally improve turfgrass by over-seeding, applying additional fertilizer (in particular nitrogen), and renovation. Therefore, the net societal loss resulting

from a ban of all phenoxy herbicides would be the increase in cost of alternative herbicides and application costs ($359 million) plus the cost of cultural improvements of turfgrass ($263 million), minus the 1992 phenoxy herbicide treatments ($254 million), or $367 million (Table 6).

Currently there are no known broadleaf weeds that have developed resistance to 2,4-D or other phenoxy herbicides in turfgrass. By increasing the use of non-phenoxy, single-site-of-action herbicides in turfgrass, there is a great likelihood of herbicide resistance developing.

Banning of 2,4-D and other phenoxy herbicides, even with the use of alternatives, would lead to a decline in the aesthetic quality and playability of sports fields and golf courses and would increase the potential of environmental contamination by increased use of nitrogen. There would be a shift to herbicides that do not have as long a history of use as do 2,4-D and other phenoxy herbicides, which have been proven effective, economical, and safe for use on turfgrass.

INTRODUCTION

The planting, growing, and maintaining of turfgrass is a multi-billion dollar industry in the United States (15). It encompasses many types of locations, facilities, and personnel. It is estimated that the value of turfgrass in the United States ranged from $20 to 30 billion in 1992 (15). In 1984, it was estimated that $1.2 billion worth of pesticides were sold to the turfgrass industry, of which $716 million was for postemergence herbicides (15). Then, as today, the phenoxy herbicides and dicamba were the predominate postemergence herbicides, with much smaller amounts of MSMA and bromoxynil being used.

Broadleaf weeds are found in turfgrass in all regions of the United States. Weeds are found in home and institutional lawns, parks, office building landscapes, cemeteries, sports fields, golf courses, and many other areas (6). Turfgrass in these areas is considered fine turfgrass, and is valued for aesthetics, usefulness in healthful exercise as sites for sporting activities, and environmental improvement though air and water filtration. Other turfgrass areas such as rough areas of golf courses, roadside turf, and parklands turf are considered rough or course turfgrass and are not included in this section of the survey.

There are two basic turfgrass types in the United States. Cool-season turfgrass, comprised of such grasses as Kentucky bluegrass, perennial ryegrass, tall fescue, bentgrass, and fine fescue; and warm-season turfgrass comprised of such grasses as bermudagrass, zoysia, bahiagrass, centipedegrass, St. Augustinegrass, buffalograss, and seashore paspalum. Other grasses are used for turf, but to a lesser extent.

Almost any broadleaf weed species can be found in turfgrass (11,14). Major broadleaf weed species are listed for several states (Table 1). Annual species are commonly found in turfgrass, but many are controlled by mowing the turfgrass. Perennial species are not controlled effectively by mowing; so these are treated generally with a herbicide. Dandelion, broadleaf plantain, buckhorn plantain, field bindweed, speedwells, clovers, curly dock, and creeping woodsorrel are but a few of the many perennial species infesting turfgrass.

Weed susceptibility to the various herbicides varies considerably. No one herbicide will control all the weed species in turfgrass and still be selective to the turf. Relative susceptibility of many turfgrass weed species are given for the United States for the commonly used phenoxy herbicides and alternative herbicides (Table 2). Many of the annual weed species may be controlled with preemergence herbicides, but annual weeds that are established, or perennial weeds, can generally only be controlled with postemergence herbicides. Preemergence herbicides are not available to control all the weed species currently found in turfgrass. One of the newer preemergence herbicides with broadleaf weed control activity (isoxaben) is not registered in all states.

Turfgrass species vary in their susceptibility to herbicides (14). Most cool-season turfgrasses are tolerant of the phenoxy herbicides, as well as newer non-phenoxy herbicides such as triclopyr and clopyralid. Tall fescue, perennial ryegrass, and Kentucky bluegrass are the most tolerant to these herbicides. The bentgrass that is commonly used on golf coarse greens will tolerate mecoprop or dicamba, but only small amounts of 2,4-D. The warm-season turfgrass species, bermudagrass, bahiagrass and St. Augustinegrass are not tolerant of these new non-phenoxy herbicides. Most of the turfgrass species will tolerate dicamba.

Estimates of turfgrass acreage in the United States have varied widely. An estimate of 15 million acres with 1.5 million in golf courses and 5 million in home lawns was given in 1974 (5). There was a 1990 estimate of 4.2 million acres of commercially maintained turfgrass (10). In 1993, an estimate of 40 million acres of turfgrass was cited by EPA (4). Furthermore EPA stated that 70 million pounds of pesticide was used for turfgrass maintenance (4). EPA personnel estimated that turfgrass acreage in homeowners lawns was about 18 million (13). This estimate did not consider other areas where turfgrass was grown.

In recent surveys in the states, weed control was a major part of the costs of turfgrass maintenance (2, 9). In Tennessee, weed control varied from 16 to 27% of the costs of maintenance from airports, schools, commercial properties, institutions, and governmental agency turf. Only fertilization and mowing the turf had costs in a similar range (2). In Pennsylvania, 60% of turfgrass management problems around homes was weed oriented and 35% around commercial and multiple dwellings; more than any other problem (9).

Properly managed, turfgrass can be vary competitive against the invasion of weeds. Cultural practices in turfgrass maintenance includes such considerations as turf species and varietal selection for the site, mowing (height and frequency), fertilization (amount, type, and timing), irrigation (frequency and amount), and verticutting or dethatching. Any of these management practices can reduce weed seedling establishment. Turfgrass specialists advise that the best deterrent to weeds is a vigorously growing turf that is adapted to the site. However, perennial weeds, once established, usually require a herbicide treatment for effective control.

Most weeds in turfgrass can be controlled selectively with herbicides. Appropriate herbicide selection for the identified weed species is required, and then application at the correct rate and time is needed for control. Although eradication of weeds is not always possible, control usually is adequate for the turfgrass to crowd out most remaining weeds.

Turfgrass weed control is practiced by the homeowner, commercial pest control applicators, lawn care operators, and managers of turfgrass and recreational facilities. It is the desire of most turfgrass managers that the turfgrass be uniform in texture and color. Presumably, this makes the turf more playable and aesthetically more pleasing.

PHENOXY REGISTRATION SUMMARY

Formulations of phenoxy herbicides are available in many different forms. The most common formulations are liquid materials that will be mixed with water and sprayed. Concentrated forms are used by commercial turfgrass managers and the lawn care industry. There are also many low concentration formulations that are used by homeowners by mixing them with water and spraying. Another method of formulating is as a premix herbicide and fertilizer product (i.e., weed and feed formulations) available as a liquid or granular. Homeowners and lawn care managers may use more than one formulation during a season. The four phenoxy herbicides available for turf are 2,4-D, mecoprop (MCPP), MCPA, and diclorprop (2,4-DP). Phenoxy herbicides are most often used in mixtures rather than alone. They are most often mixed with dicamba or triclopyr, two non-phenoxy broadleaf herbicides. These mixtures are tailored to turfgrass species, weed species, location in the country, and for the type of applicator (commercial lawn care or homeowner). In some states triclopyr is mixed with clopyralid or as a premix with 2,4-D. Clopyralid is not registered in some states.

BROADLEAF WEED LOSSES

There are no available loss estimates associated with broadleaf weeds in turfgrass. In the landscape there would be a loss in value of property if broadleaf weeds were common in the turfgrass as compared to a uniform, weed-free lawn. This would be especially apparent in residential and commercial properties. It has been estimated by home buyers that landscaping adds 15% value to the home at the time of sale or purchase (1). Real estate appraisers felt that 6 to 7% of the value of the property can be added for landscaping. Since broadleaf weeds are the most unsightly of the weed problems in turfgrass much of the concern would be for the control of these weeds. There could be losses from broadleaf weeds if found in sod because the turfgrass might not be sold if the weeds were present, but no data were found to support this potential loss.

CURRENT CONTROL METHODS

Broadleaf weed control in turfgrass is primarily with postemergence herbicides. Seedlings of some broadleaf weeds such as prostrate spurge and creeping woodsorrel are controlled with preemergence herbicides, such as, DCPA, pendimethalin, oxadiazon, dithiopyr, prodiamine, and isoxaben in states where they are registered. Isoxaben, dithiopyr, and prodiamine are not registered in all states. Combinations of oryzalin and benefin or trifluralin and benefin will control some broadleaf weeds when applied prior to weed seed germination. These materials are most often used for control of crabgrass, annual bluegrass, or other annual grass.

Respondents from the national survey indicated that 18% of the turfgrass acreage was treated with 2,4-D during 1992 (Table 3). It was either applied alone or more frequently in combination with one or more other herbicides. Application of 2,4-D was usually done once annually at an average rate of 0.68 lb/A (Table 3). MCPA was sometimes used as a substitute for 2,4-D and was applied to 2.5% of all turfgrass acreage (Table 3). The rate of MCPA was 1.1 lb/A, as compared to l lb/A of 2,4-D, to obtain similar control if used alone. Most often MCPA was combined with mecoprop and the average use rate was 0.78 lb/A. The number of applications of MCPA averaged 1.4 times per growing season (Table 3). It was estimated that without 2,4-D it would require 1.1 applications of MCPA to achieve the same control as 2,4-D. Mecoprop was used on 8.4% of the turfgrass acreage (Table 3). Average number of applications was 1.1 times per growing season at an average use rate of 0.7 lb/A (Table 3). Dichlorprop was applied 1.1 times per season at 0.83 lb/A to only 3% of the turfgrass acreage (Table 3). Dicamba can be used alone, but much of its current use is in combination with 2,4-D and mecoprop in commercial formulations. Triclopyr, a relatively new herbicide, is also used alone, in combination with 2,4-D, or in combination with clopyralid. The primary reasons that these herbicides are being used in mixtures are: (a) increased weed control, since dicamba and triclopyr are less effective on dandelion than 2,4-D, and (b) dicamba, when applied at higher rates to achieve control, can also injure trees and shrubs by root uptake through the soil.

Dandelion was reported by 73% of the respondents to be either the most important or next to the most important weed in turfgrass (Table 1). Broadleaf plaintain and buckhorn plantain were also listed as the top 3 or 4 weeds in many states. These three species are readily controlled by 2,4-D, but are less sensitive to other phenoxy or non-phenoxy herbicides. Most often a three-way mixture of 2,4-D, mecoprop, and dicamba are applied together to achieve broad-spectrum control of broadleaf weeds. Mixtures of MCPA with mecoprop plus dicamba, 2,4-D plus triclopyr, 2,4-D plus dicamba, or triclopyr plus clopyralid are used.

Determining the amount of phenoxy herbicides applied by commercial lawn care companies versus contracted application by employees proved to be difficult. In Western and Midwestern sections of the United States, more applications of phenoxy herbicides were made by employees than by commercial applicators. In the Northeast, 60% of the applications were commercial and only 40% were employee applied. In the Southeast, it was roughly even between the two types of applicators.

Homeowner purchases and herbicide application amounted to an estimated 1,646,700 pounds of 2,4-D being used in 1992, as part of the overall use of 2,4-D. In this market, 2,4-D was not sold alone, but was combined with MCPA, mecoprop, or dicamba to give broad-spectrum broadleaf weed control. Other non-phenoxy herbicides were either not available or had limited availability except when applied by licensed applicators. Application may be made with liquid formulations and applied in water, or to a lesser extent with 2,4-D on a fertilizer mixture (i.e., weed and feed).

COST OF CONTROL METHODS

Cost of broadleaf control in turfgrass. The cost of broadleaf control in turfgrass is difficult to assess. Little data exists regarding the control of broadleaf weeds with cultural control methods. Cultural methods include mowing, fertilization, aeration, verticutting or dethatching, irrigation, and overseeding. Although these cultural methods are generally thought of as growing and maintaining a good lawn, they all influence weed control. The use of herbicides is more easily assessed. An estimate in 1984 showed $716 million in sales for postemergence herbicides in turfgrass (15), by far the most of which would have been for phenoxy herbicides. Another $404 million in sales for turfgrass weed control was for preemergence herbicides. This was 91% of the total pesticide sales for turfgrass (15). Certain state surveys have indicated that weed control costs are major overall costs of turfgrass maintenance (2, 9). A survey of Pennsylvania turfgrass businesses in 1989 found that 8% of all sales was for weed control, which was 42% of all pesticide sales (9). These same businesses, when asked to indicate the three most important turfgrass management problems indicated 62, 54, and 29% for poor soils, weeds, and insect pests, respectively. In Tennessee, weeds were identified as the most frequent turfgrass-care problem by cemeteries, commercial establishments (industrial and motels), hearegarding the control of broadleaf weeds with cultural control methods. Cultural methods include mowing, fertilization, aeration, verticutting or dethatching, irrigation, and

Currently, from the survey of turfgrass specialists in the United States, it was estimated that 2,4-D was used on 18% of turfgrass acreage of 23 million acres or 4.1 million acres (Table 3). Survey information indicated 2.8 million pounds of 2,4-D (Table 4) was used at a average rate of 0.7 lb/A per season. Some applications were made alone at a use rate of l lb/A but most were in combination with other products at lower rates. The number of applications per season on treated acreage varied from 1 to 2 with 67% of the acreage receiving 1 application, 23% of the acreage averaging 1.3 applications, and 10% receiving 2 applications. The cost for herbicide was $28.1 million, and the cost of application was $103.5 million (Table 4). In addition, there was 453,000 pounds of MCPA, 1,400,000 pounds of mecoprop, and 599,000 pounds of dichlorprop used annually (Table 4). Total phenoxy herbicide cost was $64 million and application cost was $190 million per year (Table 4). The amount of other non-phenoxy herbicide use and cost was not determined in this survey.

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IMPACT OF THE LOSS OF 2,4-D

Of all the phenoxy herbicides, the greatest loss would be if 2,4-D were banned. A monetary loss would result but more importantly, there would be a major loss of control of some of the major turfgrass broadleaf weeds (Table 2). There would be an increase in use of the phenoxy herbicides MCPA and dichlorprop (Table 5). MCPA would be combined with mecoprop and dicamba for the majority of turfgrass applications. Experience has shown with this combination that it is not as effective in controlling dandelions and plantains as 2,4-D. A higher rate of MCPA would be required to get equivalent control or more applications would be required. The use of the non-phenoxy herbicides (triclopyr, clopyralid, and isoxaben in particular) would increase (Table 5). Since the phenoxy herbicides are frequently applied together or with another non-phenoxy herbicide, it is difficult to quantify acres treated.

Effects on the area treated, quantity used, material costs, and application costs. It was assumed that the total acreage treated in 1992 with 2,4-D and other phenoxy herbicides would be treated with alternate herbicides. With the reduction of 2,4-D from a ban, there would be an increase in use of the other herbicides. MCPA would replace 2,4-D in some mixtures with increased rate and number of applications per year.

In 1992, 2.8 million pounds of 2,4-D was used plus an additional 2.4 million pounds of other phenoxy herbicides. If 2,4-D were banned, total herbicide use would be 60% higher than the 1992 2,4-D use or 26% higher than all phenoxy herbicide use in turfgrass (Table 5). Also, there will be an increase in use of MCPA and dichlorprop applied alone or more likely in combination with mecoprop or dicamba. A combination of triclopyr and clopyralid also will be used on cool-season turfgrass. These herbicides are used at lower rates, but they are not as effective on some of the primary weeds as the phenoxy herbicides.

Herbicide costs will increase dramatically by 82% as compared to using 2,4-D in a broadleaf weed control program, or even 60% as compared to all phenoxy herbicides being used (Table 5). Alternative herbicides have a higher per pound cost and will need follow up applications. Though some of the newer products will be used at lower rates per acre (triclopyr and clopyralid), the costs will be higher. Isoxaben would be used at 1 lb/A, and an estimated 815,000 pounds would be used, and the estimated cost of this treatment alone would be $61 million, more than twice the cost of all the 2,4-D used (Table 5).

Application costs will increase by 49% as compared to the cost of applying 2,4-D. There would be an increase in application costs of 7% as compared to all phenoxy herbicides. Net societal loss due to banning 2,4-D in turfgrass would equal $232 million when both herbicide and application costs are considered (Table 5).

ù**Impacts of a 2,4-D ban other than changes in herbicide use patterns.** Major changes in weed control were suggested by surveyed respondents if 2,4-D were to be banned. The primary effects would be the decrease of control of dandelion and to some lesser extent broadleaf plantain and narrowleaf plantain, and an increase in the cost of materials and application as compared to 2,4-D. All other herbicides currently available are not effective for the control of dandelion (Table 2). Dandelion is one of the major broadleaf weeds in turfgrass (Table 1). There would be many consequences for lack of control and changes to alternative herbicides such as: (a) there will be some lawn-care businesses that may not be able to stay in business if satisfactory dandelion control cannot be achieved, since herbicide application and turf maintenance are a major share of their business. The cost associated with this business loss cannot be established; (b) there will be a shift to other less effective herbicides that have greater risk to landscape shrubs and trees, primarily dicamba, and to a lesser extent with triclopyr and clopyralid; (c) in southern, warm-season turfgrass (eg., bermudagrass) two of the alternatives, triclopyr and clopyralid are injurious to the turfgrass. Thus, depending upon rate used, an estimated 20% to 60% turfgrass injury can be expected; (d) due to increased application of alternative herbicides, there will be more exposure to applicators, 1oaders, and the general public; (e) there will be increased use of herbicides that do not have the history of safe use as does 2,4-D. It was stated by one of the respondents that, 2,4-D is the cheapest and safest herbicide for the control of the major broadleaf weeds in my state"; and (f) some of the products will be used at lower rates than 2,4-D.

Weed control alternatives if 2,4-D were banned. Herbicides are available as alternatives for 2,4-D, but they are not as effective on the major broadleaf weeds, dandelions and plantains (8), and they will cost more. MCPA, dichlorprop, and mecoprop will be used to replace 2,4-D in some states, but only in combination with each other or other herbicides. MCPA will be used to replace 2,4-D in the three-way mixtures currently available with an increase in rate of approximately 25% to maintain control. If dichlorprop or mecoprop are used as a substitute then rates will have to be increased to achieve similar control. Triclopyr use will increase in cool-season turfgrass. To achieve broad-spectrum weed control, triclopyr will be combined with MCPA or clopyralid. Dicamba use will increase slightly, but it cannot be safely used at rates higher than 0.25 lb/A in most turfgrass areas where tree or shrub roots may be located. On golf course fairways, where tree and shrub roots are not present, higher rates may be used.

Isoxaben, a preemergence broadleaf herbicide, will control many weeds in their seedling stage. Use of isoxaben will increase, but respondents indicate a 20% to 90% loss of weed control if isoxaben is substituted for 2,4-D. A postemergence herbicide like triclopyr may be used in combination with isoxaben. These two products have shown additive or even synergistic effects on some hard-to-kill broadleaf perennials, such as healall (3). This combination would only be available on cool-season turfgrass. Respondents from many states indicated that isoxaben did not currently fit into a broadleaf turf weed control program in their state.

In homeowner turf, it is estimated that MCPA will be substituted for 2,4-D in mixtures. This change will lead to approximately 275,000 pounds more MCPA being used. Since there will be a decrease in control of approximately 20%, there will be a need for a second application on 30% to 40% of the acreage. There will be an increase in cost to the homeowner of 35% over the current 2,4-D costs. In estimating the number of households using 2,4-D in 1992, assuming one unit of product to a household, there would have been approximately 13,640,500 units sold in households using a 2,4-D product (undisclosed surveyed sources).

Respondents also indicated that other herbicides would be used in small quantities if 2,4-D were banned. Herbicides such as metsulfuron, metribuzen, and imazaquin would be used in southern turfgrass for broadleaf weed control.

IMPACT OF THE LOSS OF ALL PHENOXY HERBICIDES

Influence on weed control. Respondents indicated that a loss of all phenoxy herbicides would cause a 10% to 50% decline in broadleaf weed management. There would not be effective herbicides for the control of many weed species common to turfgrass. In California, it was estimated that there would be a reduction of 50% in broadleaf weed control. No alternative herbicide is effective for dandelion control as clopyralid is not registered. In Florida and many other Southern States, there would be virtually no herbicide available for broadleaf weed control in many of the turfgrass areas. Respondents from Florida and Georgia indicate up to a 50% reduction in broadleaf weed control without phenoxy herbicides. The alternative herbicide, isoxaben, would not control established perennial weeds such as dandelion, plantain, woodsorrel, and wild garlic. A combination of triclopyr and clopyrlid would not control weeds like mouse-ear chickweed, healall, and speedwell. Clopyralid is not registered in all states for broadleaf weed control in turfgrass. Homeowners and lawn care companies would have to use repeat treatments to provide adequate weed control with the less effective herbicides.

Other alternative methods would be used to give some measure of weed control. Respondents indicated that there would be a change of cultural practices to try to make the cool-season turfgrass more competitive in parks, golf courses, and athletic fields. There would be an increase in the amount of nitrogen fertilizer applied and over-seeding of turf with new grasses to make the turf more vigorous. In warm-season turfgrass such as bermudagrass, there would be increased over-seeding of winter annual grasses in the fall for winter cover to decrease broadleaf weed growth.

Influence on other landscape plantings. As alternate herbicides, such as dicamba, increase in use there is a greater possibility of injury to trees and shrubs. Since dipossibility of injury to trees and shrubs. Since dicamba leaches in the soil and is more persistent than 2,4-D or other phenoxy herbicides, it can be taken up by roots of trees and shrubs causing leaf epinasty and injury. Triclopyr applications will increase as phenoxy herbicide use decreases, and there is greater concern for injury from triclopyr than from the phenoxy herbicides. Clopyralid is subject to leaching and may ca

In southern turfgrass species (bermudagrass, bahiagrass, and St. Augustinegrass), triclopyr and clopyralid are not safe to use as alternative herbicides. It is estimated that up to 80% injury to turfgrass would be experienced unless the applications could be made safer in some manner.

Influence on private business. In areas where dandelion is the main weed species, a major decrease in weed control with substitute herbicides at a higher cost would cause a major depression in the lawn care industry. This impact is difficult to estimate, but it is feasible that many would go out of business or they would have to provide other services.

Retail nurseries would also experience a decline in part of their market. The sales of herbicides and spray equipment would decrease. Since homeowners do not currently have access to some alternative herbicides, lawn care companies would have to be hired to apply materials that may require a permit to apply or that currently are only available to landscape industry personnel.

If 2,4-D and the other phenoxy herbicides were banned there would be a further psychological scare and mistrust of pesticides that would affect all lawn care services and associated businesses. Also, additional laws and regulations would probably be promulgated to restrict the uses of new pesticide products. These regulations would increase the cost of development of new herbicides and decrease the chance of alternative herbicides being developed.

Economic effects. It was estimated that there would be a direct increase of 62% in herbicide cost or

$165 million annually if all phenoxy herbicides were banned as compared to current phenoxy herbicide use (Table 6). Application costs of alternative herbicides, assuming no change in applicators, would decrease 26% or $67 million annually as compared to all phenoxy herbicides. This reduction would include fewer number of applications, though it is expected that slightly more acreage would be treated with alternative herbicides. It is likely that some of the turfgrass acreage would not be treated, and this may change the appearance of the landscape because broadleaf weeds are the most visual of the weed problems in turfgrass.

If the aesthetic value of lawns and landscapes declined because of poor broadleaf weed control, there would be a major impact on the value associated with sales of new and previous owner homes. In 1986, there were 87.9 million households in the United States, and 57 million of these households were occupied by their owners (1). In a Gallup survey, it was indicated that attractive landscaping added 15% to the selling price of a home. We do not know the total value of home real estate, nor do we know what loss would occur by having weedy turfgrass, as compared to a weed-free landscape. Using a conservative example of a $100,000 home, the 15% increase in landscape value would then make the home worth $115,000. With a 10% increase (if a 5% loss is due to weedy turf) it would only be worth $110,000, or a $5,000 unrealized profit on the home. With a 3% turnover or home buying rate (new and previous owner homes) there could be an annual loss of $8.6 billion due to weedy lawns in the landscape.

In some areas where there would not be effective weed control measures with herbicides, it

was indicated that there would be an increase in grass over-seeding and fertilization of the turfgrass to promote vigor and competitiveness of the turfgrass. An estimated cost increase of $262 million annually would be used to culturally improve turfgrass. Using the direct costs of herbicide and application for alterative weed control methods as compared to costs of phenoxy herbicides and applications used, there would be a $622 million or 59% increase in costs over phenoxy herbicide use (Table 6). This increase in non-herbicide landscape maintenance products would be a major upsurge in use of these products. This change would lead to more nitrogen being applied, with the possibility of runoff and leaching of nitrogen, which could become an environmental concern. The need for new turfgrass seed could have a major effect on seed production, but this impact has not been evaluated in this study.

There would be additional economic losses that are not easily evaluated. The psychological effect of a ban of these herbicides is not measurable, but it likely would have a major economicimpact on private businesses associated with the turfgrass industry.

Weed Control alternatives if all phenoxy herbicides were banned. In northern turfgrass areas of cool-season turf, there would be a shift to alternative herbicides such as triclopyr, clopyalid, dicamba, and to some lesser extent isoxaben (Table 6). It was estimated that the amount of triclopyr used would increase to 2.1 million and clopyralid to about 1.3 million pounds annually. Applications of triclopyr would be used alone or in combination with clopyralid. Clopyralid would need to be registered in additional states, than where it is currently registered. Dicamba use would increase to 328,000 pounds annually (Table 6).

Turfgrass seed and fertilization rates would be increased in many fine turfgrass areas to try to reduce broadleaf weeds. Other management practices such as adjusting the mower height and hand weeding may also be used.

In southern turfgrass species, applications of preemergence herbicides would need to be increased to control some broadleaf weeds. Alternative postemergence herbicides such as triclopyr and clopyalid are not safe to use on most warm-season turfgrass species. Weed control practices for perennial broadleaf weeds are not available in warm-season turfgrass. Any alternative broadleaf weed control program will not be as effective as currently available programs.

Compelling reasons to prevent the loss of phenoxy herbicides. Respondents from many states were adamant that weed control in turfgrass would decline significantly in home landscapes, industrial areas, golf courses, churches, cemeteries, roadsides, and other areas where turf is used or viewed. A high quality turf and landscape is even important for improved psychological well-being of people, as compared to a weedy turfgrass site. High quality, weed-free turfgrass also has a major impact on the price received for new and previously owned homes.

Currently for southern warm-season turfgrass species, there is nothing else available that is as safe as the phenoxy herbicides on turfgrass, applicators, family budget, and environment. In cool-season turfgrass species, there are alternative herbicides that are safe on turfgrass, but they are not as economical or will they give as broad-spectrum weed control as an application of 2,4-D. If 2,4-D were banned, there would be an increase in exposure to loader, applicator, and client because of the increase in number of applications of alternative herbicides.

The cost of weed control would also increase dramatically with a decrease in control of select turfgrass weeds. There would be some shifts in business within lawn care companies from their weed management services, to other services or they may not remain in business. There was strong feeling from the respondents that there should be no change from an inexpensive, highly effective, broad-spectrum herbicide to other products that do not have a long history of safe use.

Weed resistance management with phenoxy herbicides. Currently there is no known resistance of weeds in turfgrass to phenoxy herbicides. This is true even after 51 years of 2,4-D use in turfgrass. Goosegrass (12) and green foxtail (16) have shown resistance to trifluralin, a preemergence herbicide used in a combination product on the market. There has also been reports that smooth crabgrass is resistant to quinclorac, a herbicide that is not currently registered in turfgrass, but may achieve registration in the future (7). There is potential for an additional sulfonyl urea herbicide (halosulfuron-methyl) and a member of the imidazolinone family of herbicides (imazaquin) to be used in turfgrass. A number of weeds have been found to be resistant to these alternative herbicides. As similar herbicides are developed with a single-site-of-action, there is a greater chance for weed resistance to develop. Since weed resistance has not been demonstrated to phenoxy herbicides in turfgrass, these herbicides should be used in any program where other single-site-of-action herbicides may be introduced.

Future weed management options. Currently there are few alternatives to phenoxy herbicides for broad-spectrum, broadleaf weed control. The herbicides isoxaben and clopyralid are not registered in all states. Though isoxaben may be registered in additional states, it will not control established weeds. Also, some respondents indicated unacceptable control in state weed programs with isoxaben. Clopyalid, a non-phenoxy herbicide, is effective on many aster family weeds plus dandelion. However, it has the potential to leach; so clopyalid may not achieve registration in some states. It also would be used in combination with triclopyr to give a broader spectrum of weed control.

The new herbicide quinclorac has postemergence activity on clovers and crabgrass, but it is not a broad-spectrum, broadleaf herbicide. Halosulfuron-methyl is effective on nutsedge with unknown activity on many weeds. Imazaquin has shown activity on purple nutsedge, lesser control on yellow nutsedge, but with little broadleaf activity. It is not safe to use on cool-season turfgrass species.

Turfgrass cultural management techniques may be improved with new varieties of turfgrasses that are more competitive with weeds. These practices will only offer partial control and they would not be effective on perennial weeds that become established.

Though it may be exceedingly expensive, hand weeding may be necessary on some fine turfgrass areas for control of perennial, broadleaf weeds. It is likely, however, that if herbicides are not available to readily give control of broadleaf weeds, United States lawns and landscape will become more weedy.

Conclusions: The phenoxy herbicides and especially 2,4-D are a major, beneficial group of herbicides for broadleaf weed control in turfgrass. Control of many common and troublesome turf weeds such as dandelion, broadleaf plantain, and narrowleaf plantain will not be as good or as economical without the phenoxy herbicides. If 2,4-D was banned, there would be a 60% increase in herbicide use as compared to current 2,4-D use, and a 26% increase over current phenoxy herbicide use. There would be a herbicide cost increase of 60%, and an application cost increase of 7% as compared to current phenoxy herbicide use. All of these changes would result in a decrease in broadleaf weed control. There would be a net societal loss of $232 million primarily because of the increase in herbicide cost. If all phenoxy herbicides were banned, there would be a 29% decrease in total herbicide used as compared to current phenoxy herbicide use, but an increase of 63% in herbicide cost and a decrease in application cost of 2% as compared to current phenoxy herbicide costs. If the additional management, seed, and fertilizer costs are added, to increase the vigor and competitiveness of turfgrass, there would be a net societal loss of $367 million as compared to current phenoxy herbicide use. Also, there would be the potential loss attributed to weedy turf of $8.6 billion in unrealized value from home sales.

Broadleaf weed control in turfgrass would decline, with many areas not being treated or having less effective control. Alternative herbicides are not as effective on major turfgrass weeds as 2,4-D. In the warm-season grasses there would be few herbicides available for broadleaf weed control or there would be use of herbicides that are less safe to turfgrasses, ornamental trees, and shrubs. There would be an increase in loader, applicator, and client exposure to herbicides if 2,4-D were banned due to the required retreatments of alternative materials to achieve similar control.

There is a long history of the use of 2,4-D and other phenoxy herbicides in turfgrass. The greatest danger seems to be the accidental drift of 2,4-D onto ornamentals plants. It would be undesirable to ban phenoxy herbicides and depend upon alternative herbicides that are less effective for weed control, have greater potential for plant damage, are more expensive, and do not have proven safety records. There is no history of weed resistance with phenoxy herbicides used in turfgrass. Introducing new single-site-of-action herbicides that may be used at lower rates just to reduce herbicide poundage is scientifically unsound.

There are no new herbicides, group of herbicides, or other control measures on the horizon to take the place of the phenoxy herbicides for broadleaf weed control in turfgrass. There will be a period of reduced weed control in turfgrass in the United States if phenoxy herbicides are banned.

Conduct of the phenoxy herbicide survey in turfgrass. A special survey questionnaire was prepared and sent to turfgrass specialists throughout the United States. It was patterned after the cropland questionnaire (Appendix 7-1), except that it was modified to gain additional information on herbicide cost per application, how the herbicides were applied, extent of damage to turfgrass from the herbicides, estimated exposure to loaders and applicators, secondary impacts on the turfgrass, percent change in overall weed control, and having turfgrass weed species ranked according to importance and their control.

Survey responses were received from 32 states from which data were extrapolated for 50 states. Thirteen states were selected to conduct an in-depth analysis of the data. These states included Arizona, California, Delaware, Florida, Georgia, Idaho, Indiana, Kansas, Kentucky, Maryland, New York, Minnesota, and Ohio. These data included total turfgrass acreage, turfgrass treated with phenoxy herbicides, alternative herbicides, rate of application, number of applications, cost of material, and cost of application of each herbicide. These data were extrapolated according to the turfgrass acreage within each of the 50 states. Additional sources of information were the formulators and distributors of herbicides to the home market.

The following assumptions were made on the price of herbicides and application costs. These prices are for single products and combinations. All are determined on a per acre basis2. Herbicides and prices per pound of active ingredient(s) were: 2,4-D, $10; MCPA, $15; mecoprop, $15; dichlorprop, $15; triclopyr, $17; clopyralid, $17; dicamba. $25; isoxaben, $75; MSMA, $10; metsulfuron, $22; imazaquin, $80; bromoxynil, $10: metribuzin, $4; and diquat, $15. Combination materials include triclopyr plus clopyralid, $25; mecoprop plus dicamba, $12; triclopyr plus dicamba, $15; and MCPA plus mecoprop, $24. Cost of application used was $25 per acre.[3]

[2] Cost of herbicides and application takes into account the cost for the mix of commercial applications by lawn care operations (LCO) and commercial and private applications, but not homeowners.

[3] This cost was determined after reviewing the range of cost ($5 to $50) to apply a herbicide to golf courses, parks, commercial properties, home lawn applications by lawn care operators, sod farms, and the like.

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Table 1. Most troublesome broadleaf weeds infesting turfgrass, percent of turfgrass area infested, percent control with 2,4-D, and estimated acres of infested turfgrass in the United States during 1992.

	Dandelion			Plantain		
State	Infestation	Control with 2,4-D	Acres infested	Infestation	Control with 2,4-D	Acres infested
	%	%	(000)	%	%	(000)
California	20a	98	300	10	95	150
Delaware	50b	90	10	50	90	10
Idaho	99a	98	313	10	99	32
Indiana	75a	85	1100			
Kansas	90a	95	1200	18	90	240
Kentucky	100a	100	600	95b	95	575
Maine	5a	80	10	1	80	20
Maryland	25b	95	155	10	95	62
Michigan	95a	100	1850	80	100	1558
Minnesota	90a	95	900	40b	90	400
Missouri	80b	90	800	60	80	600
Nebraska	80a	100	273			
New York	95a	100	1040	30	90	328
North Dakota	50a	95	23	1	70	>1
Ohio	95a	95	1850	75	50	1460
Pennsylvania	90a	95	1400	90b	95	1400
South Dakota	80a	80	68			

[a]Indicates most troublesome broadleaf weed as indicated by state specialist.
[b]Indicates second most troublesome broadleaf weed.

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Table 2. Major broadleaf weeds in turf and their relative susceptibility to phenoxy and non-phenoxy herbicides applied postemergence in the United States.[a, b]

	Phenoxy herbicides			
Weed species	2,4-D	MCPA	Mecoprop	2,4-DP

Aster	F	-	-	-
Bedstraw, smooth	P	P	P-F	-
Bindweed, field	P-F	-	P-F	-
Burclover	P-F	P-F	G	F
Burdock	-	-	-	-
Buttercup	P-F	P-F	F	-
Carpetweed	G	-	-	-
Carrot, wild	F	-	-	-
Chickweed, common	P	P	G	-
Chickweed, mouseear	P	P	G	-
Chicory	F-G	F	P	-
Cinquefoil	P-F	-	-	-
Clover, white	P	P	F	F
Daisy, English	P-F	P	P-F	P-F
Daisy, oxeye	F	-	-	-
Dandelion	G	F	P	F
Deadnettle, purple	P-F	-	F	-
Dock, curly & broadleaf	F	F	-	-
Falsedandelion, Carolina	G	-	-	-
Filaree, redstem	P-F	-	-	-
Garlic, wild	F	P	P	-
Geranium, Carolina	P	-	-	-
Groundsel	G	G	-	-
Hawkweed	G	-	-	-
Healall	P	-	P	P
Ivy, ground	F	-	F	F
Knawel	P	-	P	P
Knotweed, prostrate	P	P	P-F	-
Kochia	G	G	-	-
Lambsquarters	G	G	G	-
Mallow, little	P-F	P-F	P-F	-
Medic, black	P	P	F-G	-
Moneywort	G	-	-	-
Mugwort	P-F	P	P	P-F
Mustard	G	G	-	-
Nettle, stinging	-	-	-	-
Onion, wild	F	-	P	-
Pearlwort	F	-	G	-
Pigweed	G	-	G	-
Pineapple weed	F	F	F	-

Plantain, broadleaf	G	F	P-F	F
Plantain, buckhorn	G	P-F	P-F	F
Purslane, common	G	G	-	-
Ragweed	G	G	G	-
Rocket, yellow	F-G	-	F-G	-
Shepherd's purse	G	G	G	-
Smartweed	G	-	-	-
Sorrel, red	P	-	P	F
Speedwell, common	F	-	P	-
Speedwell, corn	P	-	P-F	-
Speedwell, germander	P	P	P	P
Speedwell, purslane	-	-	P-F	-
Speedwell, thymeleaf	P-F	P	P-F	P-F
Spurge, prostrate	P	-	P	-
Spurry, corn	-	-	-	-
Spurweed	P-F	-	-	-
Strawberry,wild	P	-	P	-
Thistle, bull	G	-	-	-
Thistle, Canada	F	P-F	P-F	-
Violet	P	-	P	-
Woodsorrel, creeping	P	P	P	-
Woodsorrel, yellow	P	P	P	-
Yarrow	F	F	P	-

	Non-phenoxy herbicides				
Weed species	Bentazon	Bromoxynil	Clopyralid	Dicamba	Triclopyr
Aster	P	P	G	-	-
Bedstraw, smooth	-	-	-	P-F	F-G
Bindweed, field	P	P-F	-	G	F
Burclover	-	-	G	G	G
Burdock	P	P	G	G	G
Buttercup	P	P	-	F	-
Carpetweed	-	-	-	G	-
Carrot, wild	-	-	-	F	G
Chickweed, common	P	P	-	G	-
Chickweed, mouseear	P	P	P	F	P-F
Chicory	-	-	-	F	G
Cinquefoil	-	-	-	-	-
Clover, white	-	-	G	G	F-G

Daisy, English	P	P	F	F-G	-
Daisy, oxeye	-	-	-	-	-
Dandelion, false	P	P	P-F	-	F
Deadnettle, purple	-	-	-	G	-
Dock, curly & broadleaf	P	P	F	G	G
Falsedandelion, Carolina	P	P	P-F	F	P
Filaree, redstem	-	-	-	-	-
Garlic, wild	P	P	-	P-F	-
Geranium, Carolina	-	-	-	G	-
Groundsel	-	F-G	G	-	-
Hawkweed	-	-	-	F-G	-
Healall	P	P	P	F	P
Ivy, ground	P	P	F	F	F
Knawel	-	F-G	-	F-G	-
Knotweed, prostrate	-	F-G	-	G	-
Kochia	-	-	-	-	-
Lambsquarters	G	G	-	-	G
Mallow, little	-	F	-	F-G	-
Medic, black	-	-	G	G	G
Moneywort	-	-	-	-	-
Mugwort	-	-	F-G	P-F	P-F
Mustard	-	F	-	-	G
Nettle, stinging	-	-	-	F	-
Onion, wild	P	P	-	F	-
Pearlwort	-	-	-	-	F
Pigweed	-	F-G	-	G	F-G
Pineapple weed	-	-	G	-	-
Plantain, broadleaf	P	P	P-F	P	P
Plantain, buckhorn	P	P	F	P	F
Purslane, common	-	-	-	-	G
Ragweed	-	F-G	G	G	-
Rocket, yellow	-	-	-	F	-
Shepherd's purse	-	G	-	-	-
Smartweed	-	G	F	-	-
Sorrel, red	-	-	G	G	F-G
Speedwell, common	-	-	P	P	P

Speedwell, corn	-	-	-	P	-
Speedwell, germander	-	-	P	P	P
Speedwell, purslane	-	-	-	-	-
Speedwell, thymeleaf	-	-	P	P	P
Spurge, prostrate	-	P	-	F	F-G
Spurry, corn	-	-	-	G	-
Spurweed	-	F-G	-	F-G	F-G
Strawberry, wild	-	-	-	F	-
Thistle, bull	-	-	G	G	G
Thistle, Canada	P	P	G	G	G
Violet	P	P	-	P-F	F
Woodsorrell, creeping	P	P	-	P-F	F-G
Woodsorrel, yellow	P	P-F	-	F	F-G
Yarrow	P	P	-	G	F-G

	Herbicide combinations				
Weed species	2,4-D + 2,4-DP	2,4-D + Triclorpyr	2,4-D + Micoprop + Dicamba	MCPA + Mecoprop + Dicamba	Clopyralid + Triclopyr
<</tr>					
Aster	-	-	-	P	G
Bedstraw, smooth	F	G	F	F	G
Bindweed, field	F	-	P-F	P-F	F
Burclover	F-G	G	G	F-G	G
Burdock	G	-	G	G	F
Buttercup	F	F	F	F	-
Carpetweed	-	-	G	-	-
Carrot, wild	G	F	G	G	-
Chickweed, common	G	G	G	F-G	F
Chickweed, mouseear	G	G	G	F-G	F
Chicory	G	G	G	F-G	-
Cinquefoil	-	F	F	-	-
Clover, white	F-G	G	G	G	G
Daisy, English	F	F	F-G	F	F-G
Daisy, oxeye	G	G	F	-	-

Dandelion	G	G	G	F	F
Deadnettle, purple	-	-	F-G	F	G
Dock, curly & broadleaf	G	G	F-G	F	F
Falsedandelion, Carolina	G	-	-	-	G
Filaree, redstem	-	-	-	-	-
Garlic, wild	F	F	F	P-F	-
Geranium, Carolina	-	-	-	-	-
Groundsel	-	-	-	-	-
Hawkweed	G	G	G	-	G
Healall	F	P-F	F	F-G	P
Ivy, Ground	F-G	-	F	F	G
Knawel	-	G	-	-	-
Knotweed, prostrate	F	F	F-G	G	-
Kochia	-	-	-	-	-
Lambsquarters	-	-	G	G	F
Mallow, little	G	G	G	G	G
Medic, black	G	G	G	G	G
Moneywort	G	G	G	-	-
Mugwort	F	F	F	-	F
Mustard	-	-	-	-	-
Nettle, stinging	-	-	F	-	-
Onion, wild	F	F	F	F-G	-
Pearlwort	-	-	G	-	-
Pigweed	-	-	G	G	-
Pineapple weed	-	-	F	-	-
Plantain, broadleaf	G	G	G	G	F-G
Plantain, buckhorn	G	G	G	F	F-G
Purslane, common	G	G	G	G	-
Ragweed	G	G	G	G	F
Rocket, yellow	G	G	G	-	-
Shepherd's purse	G	G	G	G	F
Smartweed	-	-	-	-	F-G
Sorrel, red	G	G	G	F-G	G
Speedwell, common	G	F	F-G	G	F
Speedwell, corn	F	F	P-F	P-F	-
Speedwell,					

Speedwell, germander	P	P	P	P	P
Speedwell, purslane	-	-	G	G	-
Speedwell, thymeleaf	F	P	F	F	P
Spurge, prostrate	F	F-G	F-G	F	F
Spurry, corn	-	-	G	-	F
Spurweed	P-F	-	G	-	G
Strawberry, wild	F	F-G	F	-	-
Thistle, bull	G	G	G	-	-
Thistle, Canada	F	-	-	-	F
Violet	F	F	P-F	-	F
Woodsorrel, creeping	P-F	F-G	P-F	-	F
Woodsorrel, yellow	F-G	F-G	F	-	F
Yarrow	F	F-G	F	F	-

[a]P=poor control; F=fair control, often needs retreatments; G=good control; and - indicates insufficient data is available for ranking. Rankings are based on label suggestions, the sources listed below, and experiences of weed scientists.

[b]Sources: Elmore, C.L., D.W. Cudney and V. Gibeault. 1993. Turfgrass Pest Management Guidelines. UCLOTO-1, Univ. California, Div. Agric. Natural Resources, Davis, CA.
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Table 3. Survey estimates of phenoxy herbicide treated acreage and rate used in turfgrass in the United States during 1992.

Herbicide	Herbicide use		Herbicide rate	Applications per year
	Acres treated	Percent of total		
	(000)	%	lb/A	No.
2,4-D	4140	18.0	0.68	1.0
MCPA	577	2.5	0.78	1.1
mecoprop	1922	8.4	0.70	1.1
dichlorprop	721	3.1	0.83	1.0
Total	5240[a]			

[a] Does not total for column since some herbicides are used on same site of application.

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Table 4. Survey estimates of phenoxy herbicide poundage used and costs in turfgrass in the United States during 1992.

Herbicide	Pounds used	Herbicide cost $	Application cost $	Herbicide + application cost $
	-------------------(000)----------------------------			
2,4-D	2810	28101	103500	131601
MCPA	453	6791	15867	22658
mecoprop	1352	20277	52855	73132
dichlorprop	599	8991	18025	27016
Total	5214	64160	190247	254407

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Table 5. Survey estimates of herbicide use and costs in turfgrass in the United States in 1992 if 2,4-D were banned.

Herbicide	Acres treated	Pounds used	Herbicide cost $	Application cost $
	---------------------(000)----------------------			
MCPA	882	1315	19725	52312
dichlorprop	890	1893	28395	40527
triclopyr	1062	1191	20247	35363
clopyralid	750	461	7837	23767
isoxaben	668	815	61125	18398
dicamba	269	102	2550	6728
triclopyr + clopyralid	40	30	750	1987
mecoprop + dicamba	184	668	8016	9162
triclopyr + dicamba	46	68	1020	2300
metsulfuron	26	0.5	11	1300
MCPA + mecoprop	120	229	5496	4500
mecoprop	304	304	4560	7595
Total[a]	5241	7076	159732	203939

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[a] Total herbicide and application cost is $363,671,000, current herbicide and application cost of 2,4-D is $131,601,000, and difference (cost of banning 2,4-D) is $232,070,000.

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Table 6. Survey estimates of herbicide use and management costs in turfgrass in the United States in 1992 if all phenoxy herbicides were banned.

Herbicide	Acres treated	Quantity used (lb)	Herbicide cost ($)	Application cost ($)
	---------------------(000)-----------------------			
triclopyr	2019	3528	59972	163310
clopyralid	1432	1968	22463	94620
triclopyr + clopyralid	125	1069	5670	6648
isoxaben	1957	2560	191972	65528
MSMA	6	38	375	269
metsulfuron	176	2	48	4400
imazaquin	52	26	2080	1300
bromoxynil	65	38	379	2238
metribuzin	13	2	7	325
diquat	3	6	94	78
dicamba	1571	648	16199	31182
Total[a]	5520	5000	171596	187118

[a]Total herbicide + application cost is $358,714,000, additional management and seed cost is $263,062,000, total cost is $621,776,000, current herbicide and application cost of phenoxy herbicides is $254,407,000, and difference (cost of banning all phenoxy herbicides) is $367,369,000.

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Chapter 8

Phenoxy Herbicides in Small Grains in the United States

JOHN D. NALEWAJA[1]

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Abstract. Phenoxy herbicides are used widely for broadleaf weed control in small grains. Weed scientists were contacted as to the impact from possible loss of phenoxy herbicides on small grain production in their respective states during 1992. The only phenoxy herbicides registered in small grain are 2,4-D and MCPA. Both of these herbicides have unique advantages in crop safety, effectiveness on weeds, and cost. The loss of only 2,4-D would cause a shift to greater usage of MCPA, bromoxynil, dicamba, and other available alternatives. If only 2,4-D were lost, use of alternative herbicides would increase the annual cost of weed control $37.6 million in wheat, $9.0 million in barley, and $0.2 million in oat; in rye, cost would be decreased by $0.07 million. The loss of all phenoxy herbicides would increase weed control costs for alternative herbicides by $67 million in wheat, no increase in barley, $3.5 million in oat, and $0.42 million in rye. The annual net societal loss from banning 2,4-D for use in small grains in the United States would be: wheat, $112.7 million; barley, $30.5 million; oat, $4.7 million; rye, $0.5 million for a total of $148.4 million. The annual net societal loss from banning all phenoxy herbicides would be: wheat, $221 million; barley, $48.4 million; oat, $13.6 million; and rye, $0.96 million for a total of $284 million. Net societal loss, from banning either 2,4-D or all phenoxy herbicides, includes costs associated with changes in tillage and cropping practices; extra weed control cost for alternatives; reduced crop production, where alternatives may not adequately control weeds; and increased costs to consumer, from higher prices at the market. The loss does not, however, include the immediate impact on integrated pest management (IPM) by reducing options to select herbicides to optimize weed control for specific weed problems and the long-term impact of limiting herbicide options to respond to the development of weeds resistant to herbicides. The phenoxy herbicides have been used for nearly 50 years without development of major weed resistance problems, and they are still highly effective for controlling many of the important weed species infesting small grains in the United States.

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INTRODUCTION

Small grains (wheat, barley, oat, and rye) occupied 89 million acres of cropland in the United States in 1993 (17). However, average acreage in production of these four crops during 1989 to 1991 was approximately 79 million acres. Wheat alone occupied 58 million acres over the 1989 to 1991 period. Usage of 2,4-D is greater in spring wheat, which is grown mostly in the northern part of the Great Plains, than in winter wheat, which is grown throughout the United States. Winter-type small grains generally are higher yielding and more competitive against broadleaf weeds than the spring sown grains, so herbicide usage is less in winter grains than in spring grains. Barley and oat are mostly spring types with 8.7 million acres of barley and 10.3 million acres of oat, mainly grown in the northern areas of the United States.

Herbicide usage in spring wheat ranges from a low of 74% of planted acres in South Dakota to a high of 93% in North Dakota (17). The most commonly used herbicides were 2,4-D and MCPA, either alone or in combination with dicamba. Both 2,4-D and MCPA are highly effective in controlling wild mustard (see picture on the front cover), a major weed problem in small grains since the early 1900's (13). The advent of 2,4-D in 1945 allowed for a reduction in fallow and other intensive tillage and hand weeding specifically for weed control (15).

Data on phenoxy usage, losses from cancellation of registration of either 2,4-D or all phenoxy herbicides, alternative herbicides or weed control practices, changes in crop production, and major need for retaining phenoxy herbicides was obtained by contacting weed scientists or crop production specialists in each state and Puerto Rico. The original information was obtained through a mail response to a questionnaire, with telephone follow-up, and assessment team contacts with specialists in an attempt for complete coverage of crop acreage. Pesticide usage data was from various surveys and estimates by weed science or crop production specialists.

Data were extrapolated to total crop acres when data from contacts did not represent all acreage in the United States. Extrapolation percent needed to attain 100% of crop acreage were wheat 7%, oat 6%, barley all acres were represented by direct and subsequent contacts, and rye 4.3%.

Wheat. Both 2,4-D and MCPA are used for weed control in wheat production. Estimates indicated that about 14.7 million wheat acres were treated with 2,4-D, representing almost 26% of planted wheat acreage (Table 1). About 3.9 million acres or 6.8% of total wheat acreage were treated with MCPA. An estimated 5.7 million pounds per year of 2,4-D was used in wheat at an average rate of 0.39 lb/A, for an estimated annual cost of $18.2 million. MCPA use was estimated to be approximately 1.4 million pounds per year at an average rate of 0.38 lb/A, for an annual cost of $5.1 million. Use of 2,4-D is uniformly extensive regionally. For example, in the Northern Plains, 28% of wheat acreage was treated with 2,4-D; in the Southeast, 55%; in the Mountain States, 39%; and in the Pacific Region, 33%.

Barley. Both 2,4-D and MCPA are used for weed control in barley production. Survey and assessment team estimates indicate about 3.7 million barley acres were treated with 2,4-D, representing 42% of total barley acres (Table 1). About 2.1 millon acres or 24% of the total were treated with MCPA. An estimated 1.6 million pounds of 2,4-D was used on barley at 0.43 lb/A, for an annual expenditure of $5.04 million. MCPA use was estimated to be about 854,000 pounds at 0.40 lb/A, for an annual expenditure of $3.1 million. Use of phenoxy herbicides is extensive in most regions of the United States. In the Southeastern, Mountain, and Lake States, about 50% of barley acres were treated with phenoxy herbicides. About 42% of barley acres in the Lake States, 34% in the Pacific, and 20% in the Northeast and Appalachian States were treated with phenoxy herbicides.

Oat. Both 2,4-D and MCPA are used for weed control in oat production. MCPA was more widely used, being applied to 1.5 million acres or about 14.4% of total oat acres; 2,4-D was used on 1.1 million acres or 10.6% of oat acres (Table 1). An estimated 400,000 pounds of 2,4-D was applied each year to oat at an average rate of 0.36 lb/A, for an annual expenditure of $1.28 million. MCPA use was estimated to be 595,000 pounds per year applied at 0.40 lb/A, for an annual expenditure of $2.22 million. Acres treated was most extensive in the Mountain States (33%) and Southeastern States (33%), although significant acreages were treated in the Northern Plains (16%), Northeast (29%), Mississippi Delta (10%), and Lake States (9.2%).

Rye. About 12.3% or 218,000 acres of rye were treated each year with about 124,000 pounds of 2,4-D at a rate of about 0.57 lb/A (Table 1). Average annual expenditure for 2,4-D was estimated to be about $396,000. The states with widespread 2,4-D use in rye include South Carolina and Oregon where 50% of the acreage was treated, Georgia with 30%, and Minnesota and North Dakota each with 20% of the acreage treated.

Wild mustard continues to be an important weed problem in spring seeded small grains even with extensive usage of 2,4-D since the late 1940's (3, 19). Wild mustard seed has long viability in the soil, so seed produced in a given year in the crop rotation will cause infestations for many subsequent years. In North Dakota, the inclusion of sunflower in the cropping system in the 1960's helped maintain the wild mustard soil seed bank because of poor control in sunflower.

The high cost of labor and access difficulty because of narrow rows makes hand weeding prohibitive as a weed control method in small grains. Furthermore, the soil erosion associated with intensive tillage for seedbed preparation or fallow limits these practices for weed control by conservation-minded growers. Spring small grains are grown in areas not adapted to many alternate crops to aid in weed management, which accounts for the extensive herbicide usage in the spring wheat area. Sunflower included in the crop rotation in the 1960's may have reduced the occurrence of wild oat and green foxtail, but increased the occurrence of wild mustard.

PHENOXY HERBICIDE REGISTRATION SUMMARY

MCPA and 2,4-D at 0.25 to 1.4 lb/A are registered for broadleaf weed control in wheat, barley, oat, and rye. The 1.4 lb/A rate is for emergency perennial broadleaf weed control in wheat and as a harvest aid in wheat, barley, and oat. Individual labels differ as to rates for the varirate is for emergency perennial broadleaf weed control in wheat and as a harvest aid in wheat, barley, and oat. Individual labels differ as to rates for the various small grains. Oat is more susceptible than the other small grains to phe

LOSSES FROM BROADLEAF WEEDS

Broadleaf weed competitiveness with small grains depends on the specific weeds present, and on whether the soil fertility, moisture, and temperature favor the crop or the weeds (2, 5, 6, 14). Wild mustard at 100 plants per square yard caused a 30% wheat yield loss, but the same number of wild buckwheat plants caused only a 10% wheat yield loss. Wild mustard populations of 25 to 93 plants per square yard caused an average 29% wheat yield loss that was reduced to 13% by a postemergence treatment with 2,4-D at 0.25 lb/A. Wild mustard control from 2,4-D varied from 48 to 100% population reduction, and surviving wild mustard plants were severely injured but still green at harvest. Even though 2,4-D did not completely kill all wild mustard growth, yields of sprayed wheat equalled that of wheat hand weeded at the time of spraying, indicating that 2,4-D was not injurious to wheat and that the 13% yield loss was from wild mustard competition prior to herbicide treatment. MCPA can safely be applied earlier than 2,4-D to small grains to reduce early competition from susceptible weeds, such as wild mustard.

Kochia is an important weed problem in the Great Plains small grain growing area. Competition to small grains from kochia usually is severe. Wheat yield losses of 21% to 50% from 106 plants per square yard were observed in five experiments conducted over 2 years (1). In these experiments, 2,4-D at 0.5 lb/A gave 88% to 100% kochia control and increased wheat yield an average of 142%. Bromoxynil at 0.25 lb/A increased wheat yield 140% and dicamba at 0.12 lb/A increased yield 139%. These data show the importance of kochia control in wheat production. Kochia probably is equally as competitive in oat and barley, but information was not found on direct yield losses. Barley is only slightly more competitive than wheat with wild oat (5), so broadleaf weeds also would probably be slightly less competitive in barley than in wheat. Oat also is slightly more competitive than wheat with weeds (5). One hundred wild mustard plants per square yard caused a 56% wheat yield loss, but only a 44% oat yield loss. Yield losses from uncontrolled broadleaf weeds in all small grains can be large even though differences occur among the specific crops and weeds.

Information on competition from various densities of other broadleaf weeds in small grains are less detailed. Canada thistle at 3 plants per square yard caused a 17% yield loss in wheat (7), and field bindweed at 7 plants per square yard caused an 18% yield loss (8). Grasses are not controlled by 2,4-D, and it does not control all broadleaf weed species, but 2,4-D reduced weed losses from 14% to 6% in 142 wheat fields with a mixture of weed species over 3 years in Manitoba (6).

Broadleaf weeds occurring in small grains are common lambsquarters, redroot pigweed, Russian thistle, prostrate pigweed, common cocklebur, flixweed, ragweed, dwarf mallow, marshelder, leafy spurge, skeletonweed, common milkweed, yellow woodsorrel, dandelion, smartweeds, prickly lettuce, fumitory, dock, hedge bindweed, shepherd's-purse, perennial sowthistle, blue mustard, wild garlic, night flowering catchfly, henbit, chickweed, gromwell, coast fiddleneck, and others (12). The proper formulation of 2,4-D, applied at the proper time, kills or gives above ground control of many of these weeds; but 2,4-D does not control mallow, common milkweed, yellow woodsorrel, some smartweeds, fumitory, false chamomile, or nightflowering catchfly. Usually several weed species occur in a single field, so 2,4-D or other phenoxy herbicides are important components in tank mixtures with other herbicides in order to achieve broad-spectrum weed control.

Wheat yield was increased 19% by the use of 2,4-D and 13% by MCPA averaged over 15 experiments from 1982 through 1991[2] . The experiments were conducted at various locations in North Dakota and involved numerous combinations of weed species. The greater benefit from 2,4-D than MCPA, as shown by higher wheat yields, probably reflects the better control of Russian thistle and kochia with 2,4-D.

[2] Weed Science Annual Reports. 1982 to 1991. Dep. Plant Sci., North Dakota State Univ., Fargo, ND 58105.

CURRENT CONTROL METHODS

Herbicides applied postemergence are the most common method of broadleaf weed control in small grains. Tillage is used to control weeds during seedbed preparation and after harvest. Small grains are seeded in rows, usually less than 1 foot apart. Recently small grains have been seeded with equipment that broadcasts the seed over about a 6-inch wide area. In either case, cultivation during the growing season is not feasible. Thus, selective herbicides are well adapted to small grain production. Nonselective herbicides may even eliminate the need for tillage prior to planting and thus facilitate more timely crop seeding. Timely seeding in the spring is essential to optimize small grain yields, and timeliness is often more important to yield than controlling weeds2. Large equipment for tillage and seeding have made timely seeding of large acreages possible, which has contributed to recent small grain yield increases. The practice of delayed seeding of spring-sown small grains, which employed tillage to stimulate weed seed germination and subsequent tillage to control the emerged weeds, is no longer a general practice.

The long list of herbicides registered for broadleaf weed control in small grains indicates the importance of weeds, the dependence of growers on herbicides for weed management, and the diversity of weeds in small grains throughout the United States (Table 2). Some of the herbicides listed are specifically for grass weed control, but they may also control certain broadleaf weeds. For example, imazamethabenz controls wild mustard even though it is used mainly for wild oat control. Trifluralin, propanil, and metribuzin are used for grass weed control in small grains, but they also control many broadleaf weeds. Glyphosate and paraquat give broad-spectrum weed control prior to seeding or emergence of small grains, and thus are used as a substitute for tillage. Certain herbicides are restricted to specific small grain cultivars or certain growing regions; chlorsulfuron is restricted to areas with relatively low pH soils to reduce crop damage from residual herbicide, and diuron and metribuzin are restricted to only winter wheat grown under specific climatic conditions. Sulfonylureas, clopyralid, dicamba, picloram, and propanil are usually used in combination with a phenoxy herbicide to increase the weed control spectrum and crop safety and to reduce the potential for weed resistance.

Hand pulling of weeds in small grains was a common practice prior to the introduction of the phenoxy herbicides in 1945. However, present labor costs make hand pulling of weeds in small grains economically unfeasible. Furthermore, the drudgery of pulling weeds and the difficulty of accessing narrow rows is not readily accepted by laborers.

Hand hoeing for broadleaf weed control in small grain fields seeded in 6-inch rows would be difficult and unacceptable because of the damage to the crop from the hoe and hoer. Furthermore, weeds growing within the crop row could not be destroyed by hoeing, and yield losses would still occur.

Rotation of small grains with crops having a different life cycle than small grains is practiced in areas with adapted marketable crops. Crops with an optimum seeding date later than small grains also allows for control of early weed flushes by tillage or herbicides prior to crop seeding.

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COST OF CONTROL METHODS

The cost for various herbicides for broadleaf weed control in small grains is presented in Table 2. Phenoxy herbicides, 2,4-D and MCPA, are the lowest priced of those that are often applied alone. Phenoxy herbicides give excellent control of wild mustard, which is the major weed problem in spring seeded small grains. Phenoxy herbicides, even when only providing partial control of weeds such as kochia, are important in mixture with other herbicides in order to delay the occurrence of weed resistance to sulfonylurea herbicides or other herbicides.

Delayed seeding involves an average of 1.5 extra cultivations for weed control at $5.71/A (18) and a 95,102 Kcal/A mechanical energy input as compared to 2,4-D at 0.25 lb/A at $0.80/A for chemical and $2/A for application and a 4,318 Kcal/A input for both chemical and mechanical energy (15). Furthermore, delayed seeding reduced small grain yield from 13% to 53%, depending on growing conditions in a given season (9).

Hand pulling wild mustard required 2 hours per acre walking and looking and an additional pulling time of 1.4 to 4.0 seconds per plant, with time per plant decreasing as density increased to 450,000 plants per acre (4). The cost for hand pulling wild mustard from an acre of land varied from $15.50 for 5,000 weeds removed to $1097.50 for 435,000 plants per acre. Thus, 2,4-D at about $3.00/A (for chemical and application) would be much less costly than the $15.50/A to hand pull a low wild mustard infestation of only one plant per square yard.

Hand hoeing is not practical in small grains, but required 97.5 hours per acre for wild oat removal (15), which is slightly greater than what would be required for removal of a tap-rooted broadleaf weed. However, wheat yield was only increased 4 bushels per acre with hoeing as compared to 20 bushels per acre with herbicide treatment. Hoeing wild mustard would be less feasible than hand pulling because of the greater injury to the small grain from the hoe.

Fallow is practiced for moisture conservation and weed control in the drier small grains growing areas of the United States. The practice of fallowing in small grain rotations has effectively reduced weed densities (16). However, the cost of not producing a crop plus the cost of tillage during the fallow year may be economically devastating to the grower. Conventional fallow consisted of up to 5 field cultivations per year to control weed growth (9). Chemical fallow uses herbicides such as glyphosate, paraquat, dicamba, and 2,4-D to control weeds without soil-eroding or moisture losing cultivation. Energy for 5 cultivations required 316,000 Kcal/A, but three applications of glyphosate at 0.18 lb/A plus 2,4-D at 0.25 lb/A only required 22,500 Kcal/A (15). The 5 cultivations would cost $19.05/A, and the herbicides would cost $16.44/A, considering $2.00/A in application cost each time.

IMPACT OF THE LOSS OF 2,4-D.

Wheat. Banning 2,4-D in wheat production while leaving other phenoxy compounds available would cause growers to substitute MCPA on 77% of those acres currently treated with 2,4-D. Both dicamba and bromoxynil would each be used on 8% of those acres currently treated with 2,4-D. Approximately 2.8 million pounds of alternative herbicides would be applied as compared to 5.7 million pounds of 2,4-D. However, cost for alternatives would increase herbicide expenditures by $37.6 million.

Yield loss estimates vary considerably for the loss of 2,4-D. Although no loss was predicted in Kansas, yield losses of up to 20% were expected in Kentucky and Oregon; 15% in Delaware; and 10% in Minnesota, Tennessee, Louisiana, and Colorado. The average yield loss for all wheat, if 2,4-D were lost, was 0.9%.

The loss of 2,4-D for weed control in wheat would reduce wheat production by 19.1 million bushels and cause costs of production to increase by $4.18/A, for a total estimated increased annual production cost of $56.6 million (Table 3). The price of wheat would increase 1.1%, resulting in a net increase in costs to consumers of $72 million. The resulting net societal loss if 2,4-D were banned for use in wheat in 1992 was estimated as $112.7 million Table 4.

Barley. Banning 2,4-D, but allowing other phenoxy herbicides to be used in barley, would cause growers to use MCPA on 77% of acres currently treated with 2,4-D. Bromoxynil would be applied on 12%, tribenuron on 8%, and dicamba on 2% of acres currently treated with 2,4-D. Total herbicide usage would decrease from 1.6 million pounds of 2,4-D to about 1.3 million pounds of alternative herbicides, but because alternative herbicides are much more expensive than 2,4-D, herbicide cost would increase $9 million.

The average yield loss without 2,4-D for weed control in barley would be 2.1%. Yield loss was estimated at 20% in Kentucky, 15% in Nebraska and Tennessee, and 10% in Delaware; but most other states indicated no yield reduction from loss of only 2,4-D.

Weed control production costs in barley would increase by $12.88 million and barley grain produced would be reduced by 9.04 million bushels if 2,4-D were lost (Table 3). Net societal cost from loss of 2,4-D for use in barley would be $30.5 million (Table 4), considering a price elasticity of -0.019 and a price increase of 2.3%.

Oat. Banning 2,4-D, but allowing other phenoxy herbicides to remain in use, would cause most oat growers to shift to MCPA. About 86% of acres currently treated with 2,4-D would receive a MCPA application. Bromoxynil would be used on 12% of acres currently treated with 2,4-D, but dicamba would be used on the remaining 2%. Yield loss estimates range from 20% in Georgia and Kentucky; to 10% loss in Alabama, Arkansas, and Wyoming; to 3% in both North and South Dakota; and to 2% in Kansas. Cost of weed control with herbicides would increase from about $1.8 million under the current situation to about $2 million. Oat production cost would increase $3.7 million or $2.92/A (Table 3), and net grower revenue would decrease $3.8 million. The loss of 2,4-D for weed control in oat would reduce production 0.4% at a $4.7 million net societal loss (Table 4), assuming a -0.97% price elasticity and a 0.4% increase in the price of oat.

Rye. If 2,4-D were unavailable for use in rye production, the most popular alternative herbicides would be MCPA, bromoxynil, and dicamba. Approximately 64,000 pounds of these herbicide alternatives would be used as compared with 124,000 pounds of 2,4-D, and usage would be: MCPA 69%, bromoxynil 26%, and dicamba 5%. The cost of weed control, for acres currently treated with 2,4-D, would decline from $394,000 to $328,000 because many acres would not be treated with any herbicide. For example, no alternative weed control methods would be used on 80% of the acres currently treated with 2,4-D in North Carolina, on 70% in Michigan, and on 60% in Virginia. Yield loss estimates without 2,4-D range from 20% in Oregon, 15% in Georgia, 10% in Nebraska, and 5% in Michigan and Virginia. The weighted average yield loss estimate, if 2,4-D were lost, is 0.8%. Net revenue loss, which summarizes the yield effect and cbromoxynil, and dicamba. Approximately 64,000 pounds of these herbicide alternatives would be used as compared with 124,000 pounds of 2,4-D, and usage would be: MCPA 69%, bromo(Table 4).

WEED CONTROL ALTERNATIVES IF 2,4-D WERE LOST

MCPA would be the main alternative to 2,4-D. MCPA is presently used in oat and for early treatments in other spring grains because it is safer than 2,4-D on small grains. Dicamba or bromoxynil is applied at an early stage to prevent injury from dicamba or for better control of small weeds by bromoxynil. MCPA is less effective than 2,4-D on many weeds, such as Russian thistle, kochia, wild buckwheat, and redroot pigweed. Thus, MCPA would require application in combination with other herbicides or at higher rates if used alone. Replacement of 2,4-D by MCPA in combination with other herbicides would control most weeds in wheat. The loss of only 2,4-D probably would not reduce grain yields greatly, but it would increase the cost of weed control and allow more rapid development of weed resistance to the sulfonylurea herbicides and other herbicides.

IMPACT OF THE LOSS OF ALL PHENOXY HERBICIDES

Wheat. If all phenoxy herbicides were banned, farmers would likely use bromoxynil on 52% and dicamba on 28% of the acres currently being treated with 2,4-D. Tribenuron would be applied to 6%, and a number of other materials would be used on the remaining 14% of acres currently receiving 2,4-D. Use of herbicides would be reduced from 5.7 million pounds of 2,4-D to 1.1 million pounds of alternatives, but at an estimated added cost of $67 million. Non-chemical weed control methods were not expected to be used by wheat growers. In a significant number of states, no substitute weed control methods were expected to be used if regulatory action removed either 2,4-D or all phenoxy herbicides; in Kentucky 90% of currently treated acres would have no alternative weed control applied, in Louisiana 60%, in Nebraska 50%, and in Michigan 25%.

If phenoxy herbicides were banned, predicted yield losses could reach 20% in California and New

Mexico, 10% in Utah, and 8% in North Dakota. Regionally, the Mountain States and Appalachia are expected to experience up to a 7.6% yield loss. The Pacific States could see yields reduced 5.4%, the Southeast 3.1%, and the Lake States 3.4%. A 1.8% yield loss could be expected in the Cornbelt. The weighted average yield effect of a loss of all phenoxy herbicides is a decrease of 2.2% nationally.

Loss of all phenoxy herbicides would increase the farm-level wheat price 1.1% because of a 2.2% yield reduction. The resulting estimated decrease in consumer surplus with the loss of all phenoxy herbicides is $72.6 million, while the increase in production costs could total $72.8 million or $4.18/A (Table 3). Net revenue could decline by $148.6 million (Table 4) or a loss of $3.90/A, while non-users of phenoxy herbicides would have a net return increase of $1.26/A from the increase in wheat price.

There would be significant regional differences in impacts from the loss of phenoxy herbicides. Delta States users of phenoxy herbicides who participate in government programs could have returns decline by $20.16/A, in Pacific States by $16.03/A, and in Northeast States by $14.41/A. In the Northern Plains the impacts would be a loss of $4.24/A, but only a negligible $0.09/A loss in the Southern Plains. Non-participants in government programs would experience similar net revenue losses though uniformly less severe. Growers who are not currently using phenoxy herbicides and who are not commodity program participants could experience revenue gains of up to $2.15/A. The net societal effect in 1992 for loss of phenoxy herbicides for wheat is an estimated annual loss of $221 million (Figure 1 and (Table 4).

Barley. If all phenoxy herbicides were banned, farmers would use bromoxynil on 75% of acres currently treated with 2,4-D, dicamba on 15%, tribenuron on 3%, and other herbicides, or nothing, on the remaining 7%. Herbicide usage with a loss of all phenoxy herbicides is expected to be 218,000 pounds as compared with the 2,454,000 pounds of 2,4-D and MCPA currently used. The reduction in quantity of herbicide usage would occur because many respondents indicated that acreage would go untreated if phenoxy herbicides were banned and because alternative herbicides would be used at lower rates. For instance, no substitute weed control methods would be used on 90% of Kentucky barley-acres currently treated with phenoxy herbicides, 50% in Michigan, 35% in California, and 30% in Nebraska. Non-chemical weed control methods were not expected to be used by barley growers.

Thus, the total cost for alternative herbicides would be about $8.0 million, the same as the present $8.0 million for 2,4-D and MCPA. Banning of all phenoxy herbicides could cause yield losses of 30% in Maine, 20% in Kentucky, 15% in Nebraska, and 10% in Minnesota. Regionally, there would be a 6.5% yield loss in the Mountain States and 4.4% in Northern Plains with the loss of phenoxy herbicides. The weighted average United States yield reduction from a loss of all phenoxy herbicides was estimated at 3.8% resulting in a farm-level price increase of 2.3%. The resulting estimated loss to consumers was $20.4 million and the increase in production costs could total $21.5 million or $3.62/A (Table 3). Net revenue could decline by $28 million (Table 4) or a loss of $4.42/A on acres currently being treated with phenoxy herbicides because of lower yield and higher cost of alternatives, while acres not previous being treated with phenoxy herbicides could realize a $2.56/A increase in returns because of increases in barley prices.

Regional impacts vary; in the Northeast, annual returns on treated acres would decrease by $14.34/A, in the Mountain States by $9.74/A, and in the Northern Plains by $7.10/A for participants in government programs. Users of phenoxy herbicides, not in government programs, would experience similar though smaller losses. Non-users of phenoxy herbicides, not in government programs, would generally benefit from a phenoxy herbicide ban with increases of up to $3.00/A in the Lake States.

The net societal loss in 1992 from a ban of phenoxy herbicides for use in barley is estimated at $48.4 million (Figure 1 and Table 4).

Oat. If all phenoxy herbicides were banned, bromoxynil would be used on 80% of those oat acres currently being treated with phenoxy herbicides. Dicamba would be applied to 18% of those acres and clopyralid to 2%. Use of alternative herbicides for weed control would increase cost by $3.5 million annually. No non-chemical weed control methods were expected to be used. Many states reported that growers would plant oat acres to another crop. A number of states expected that no weed control methods would be used on large proportions of acres currently treated with phenoxy herbicides if they are lost to oat production, including: Arkansas (100%), Kentucky (84%), Alabama (50%), Michigan (25%), and Kansas (20%). If all phenoxy herbicides were banned, oat yield losses were predicted to occur in many states, including North Dakota (20%), South Dakota (17%), Pennsylvania (20%), Kansas (25%), and Minnesota (10%). Regionally, Appalachian States would incur a 20% yield loss, Southeast States 11%, and Delta States 10%. The overall weighted average yield loss estimate, however, was only 1.6% because many acres were predicted to have no yield loss.

The estimated average yield loss of 1.6% would lead to a farm price increase of 1.7% if all phenoxy herbicides were lost (Table 3). Production cost would increase $6.7 million or $2.92/A (Table 3), and net grower revenue would decline by $12.6 million (Table 4). The net societal effect of a phenoxy herbicide ban in 1992 would be an annual loss of $13.6 million (Figure 1 and Table 4).

Rye. If all phenoxy herbicides were lost for rye, about 43,000 total pounds of bromoxynil and dicamba would be used as alternatives, with 85% of acres currently being treated with phenoxy herbicides would receive bromoxynil and 15% dicamba at an added cost of $423,000. The present phenoxy herbicide annual usage in rye is 124,000 pounds. If all phenoxy herbicides lost their rye registration, yield could be expected to decline by 1.2%, and production costs to increase by $821,000 or $3.94/A (Table 3). No elasticity values were available for rye, no consumer impacts were estimated, and the total economic effect of losing phenoxy herbicides was expressed as the net revenue loss from yield declines and production cost increases. The annual net societal loss in 1992 for banning phenoxy herbicide use in rye would be $965,000 (Figure 1 and Table 4).

WEED CONTROL ALTERNATIVES IF ALL PHENOXY HERBICIDES WERE LOST

Alternatives to phenoxy herbicides could adequately control most broadleaf weeds in small grains, but at a greater cost. Metsulfuron could control wild mustard, the main weed in spring grains for which phenoxy herbicides are applied alone. Metsulfuron would increase control cost by $2.03/A and could be used only in fields with a soil pH below 7.9 and those not being rotated to susceptible crops. Tribenuron or thifensulfuron plus tribenuron could be used on small grain fields not acceptable for metsulfuron, but at about $4.10/A more than for a phenoxy herbicide.

Dicamba in tank mixture with metsulfuron, tribenuron, or thifensulfuron plus tribenuron would often replace the dicamba-MCPA mixture currently applied for broad-spectrum broadleaf weed control. The added costs and use restrictions have already been discussed.

Bromoxynil alone controls many small broadleaf weeds, but is effective on more weed species and on larger weeds when applied with MCPA or 2,4-D. The use of bromoxynil would increase the spectrum of weeds controlled, but at a cost of $5.44/A above that of 2,4-D or MCPA alone.

COMPELLING REASONS TO RETAIN PHENOXY HERBICIDES

1. Phenoxy herbicides economically control many important broadleaf weeds in small grains.

2. Phenoxy herbicides have been used widely, with safety to humans and the environment, for 51 years.

3. Weeds generally have not developed resistance to phenoxy herbicides even after 51 years of usage.

4. Phenoxy herbicides are important components of weed resistance management, either in mixtures with other herbicides or as separate applications in alternate years.

5. The small grain acreage treated with herbicides would decrease and yields would be reduced if the phenoxy herbicides were lost.

6. If phenoxy herbicides were lost, fallow and more intensive tillage would increase with accompanying soil losses to erosion by wind and water.

7. Phenoxy herbicides are especially effective on specific weeds that need to be controlled in IPM programs.

WEED RESISTANCE MANAGEMENT

Kochia, Russian thistle, and prickly lettuce have developed resistance to sulfonylurea herbicides. Kochia, a highly competitive weed with small grains, is not always controlled by phenoxy herbicides. Kochia has the potential of also developing resistance to 2,4-D and dicamba in addition to sulfonylurea (1). These herbicides have all been incorporated into resistance management schemes to delay the development of weed resistance to each component. The availability of 2,4-D is important to provide another mode-of-action for use in herbicide mixtures or in herbicide rotation resistance management systems.

FUTURE WEED MANAGEMENT

Phenoxy herbicides, because of their long time usage without any known adverse environmental effects, are accepted components of most sustainable agricultural systems. Alternatives to phenoxy herbicides are more costly and are more recent in development, which has limited their acceptance in sustainable agriculture programs. The primary goal of future weed management will be to use various control practices, including herbicides, to minimize costs to the producer while eliminating, or reducing, adverse effects to the environment. For example, 2,4-D and MCPA in small grains are highly effective in controlling many weed species. Controlling these weeds in small grains have reduced their occurrence in subsequent crops. Phenoxy herbicides will continue to be required, alone or in mixture with other herbicides, in combination with tillage and cropping practices in preventing specific weed populations from developing (10,11).

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Table 1. Yearly production, price, and phenoxy herbicide use for small grains in the United States during 1992.

Crop and herbicide	Acres in production [a]	Bushels produced [a]	Price	Phenoxy herbicide use[b]: Acres treated		Pounds used	Use rate
(000)	(000)	$/bu	(000)	%	(000)	lb/A	
Wheat	57,912	2,251,250	2.92				
2,4-D				14,700	25.5	5,700	0.39
MCPA				3,900	6.8	1,379	0.38
Barley	8,757	430,298	1.92				
2,4-D				3,700	42.3	1,600	0.43
MCPA				2,137	24.4	854	0.40
Oat	10,386	324,546	0.77				
2,4-D				1,100	10.6	400	0.36
MCPA				1,500	14.4	595	0.40
Rye	1,770	11,195	1.56				
2,4-D				218	12.3	124	0.57
Total	78,825			27,255	34.6	10,652	0.39

[a] Average per year for 1989 to 1991.

[b] Based on 1993 survey for 1992 data.

Table 3. Estimated changes in production and in cost of production of small grains in the United States during 1992 with the loss of either 2,4-D or all phenoxy herbicides.

Crop	Assuming loss of 2,4-D: Loss of production – Bushels	Percent	Cost increase per treated acre [a]	Total cost change	Assuming loss of all phenoxy herbicides: Loss of production – Bushels	Percent	Cost increase per treated acre [b]	Total cost change
	(000)	(%)	$	$ (000)	(000)	(%)	$	$ (000)
Wheat	19,136	0.9	4.18	56,511	49,528	2.2	4.18	72,800
Barley	9,036	2.1	3.62	12,884	12,909	3.8	3.62	21,500
Oat	1,298	0.4	2.92	3,716	3,895	1.6	2.92	6,700
Rye	91	0.8	1.52	329	137	1.2	3.94	821

[a] Refers to acres estimated to have been previously treated with 2,4-D.

[b] Refers to acres estimated to have been previously treated with any phenoxy herbicide.

Table 4. Estimated economic effects of the loss of either 2,4-D or all phenoxy herbicides in small grain production in the United States during 1992.

	Assuming loss of 2,4-D	Assuming loss of all phenoxy herbicides

Crop	Price change	Net revenue change	Consumer effect	Net societal effect	Price change	Net revenue change	Consumer effect	Net societal effect
	%		$ (000)		%		$ (000)	
Wheat	1.1	-40,997	-71,734	-112,731	1.1	-148,600	-72,600	-221,000
Barley	2.3	-11,303	-19,160	-30,463	2.3	-28,000	-20,400	-48,400
Oat	0.4	-3,755	-984	-4,726	1.7	-12,600	-979	-13,600
Rye	0.0	-473	0	-473	0.0	-965	0	-965

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Table 2. Herbicides used for broadleaf weed control[a] in small grains in the United States.

	Small grain				Average use rate	Average herbicide cost
Herbicides	Wheat	Barley	Oat	Rye		
				lb/A	$/A	
Bromoxynil	R[b]	R	R	R	0.250	6.64
Chlorsulfuron	R	R	R	--	0.016	6.42
Clopyralid	R	R	R	--	0.060	9.17
2,4-D	R	R	R	R	0.375	1.20
Dicamba	R	R	R	--	0.125	2.44
Diuron	R	--[c]	--	--	0.812	4.11
Glyphosate	R	R	R	R	0.190	2.58
Imazamethabenz	R	R	--	--	0.190	8.40
MCPA	R	R	R	R	0.375	1.37
Metribuzin	R	R	--	--	0.312	10.69
Metsulfuron	R	R	--	--	0.004	3.23
Paraquat	R	R	--	--	0.500	6.52
Picloram	R	R	R	--	0.016	0.66
Propanil	R	R	R	--	1.000	5.70
Thifensulfuron + tribenuron	R	R	R	--	0.021	5.30
Triasulfuron	R	R	--	--	0.018	5.24
Tribenuron	R	R	--	--	0.011	3.92
Trifluralin	R	R	--	--	0.500	3.90

[a] Some of the herbicides listed are used primarily for grass control, but they also control certain broadleaf weeds.
[b] R indiates registered for use on the crop with the Environmental Protection Agency.
[c] The herbicide is not registered on this crop.

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Chapter 9

Phenoxy Herbicides in Flax, Millet, Rice, Wildrice, Seed Crops, Sugarcane, Pea, and Fallow in the United States

JOHN D. NALEWAJA[1]

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Abstract. Phenoxy herbicides are currently used for broadleaf weed control in flax, millet, rice, wildrice, grass and alfalfa seed production, sugarcane, pea, and fallow. Weed scientists in the various states and Puerto Rico were contacted to estimate the impact of the possible loss of phenoxy herbicides for the production of these crops plus for managing fallow acres. Phenoxy herbicides are important for weed control in these crops and fallow because of their effectiveness in controlling many broadleaf weeds at a low cost. For example, MCPA is essential for wild mustard control in flax, 2,4-D for common waterplantain control in wildrice and for texasweed in sugarcane, and 2,4-DB for broadleaf weed control in production of weed-free alfalfa seed. Effective soil erosion control on fallow requires 2,4-D alone or in mixture with glyphosate for broadleaf weed control as a substitute for soil-eroding tillage. Phenoxy herbicides are a vital supplement to cultural practices for weed control in most of these crops. The net societal cost in the United States for the loss of phenoxy herbicides for these crops would be: flax, the loss of MCPA, $1.6 million; millet, loss of 2,4-D, $588,000; rice, loss of 2,4-D and MCPA, $6.7 million; wildrice, loss of 2,4-D, $1 million; grass and legume seed, loss of 2,4-D, MCPA and 2,4-DB, $5.7 million; sugarcane loss of 2,4-D, $51.1 million; pea, loss of MCPA and MCPB, $8.6 million; and fallow, loss of 2,4-D, $125 million. The loss of only 2,4-D for weed control in these crops (and fallow) is estimated to cause an annual net societal cost of $189 million and the loss of all phenoxy herbicides, $200 million.

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INTRODUCTION

Flax, millet, rice, grass and alfalfa seed, sugarcane, pea, and fallow are crops or production practices using phenoxy herbicides. The particular phenoxy herbicide used varies with the crops. Phenoxy herbicide usage in these crops does not account for a large part of their total usage in the United States, but they are essential to the continued production of these crops and cropping practices. There are no alternatives for broadleaf weed control in wildrice, and phenoxy herbicides provide an important economical alternative or supplement to other herbicides for broad-spectrum weed control in the remaining crops. The low cost of 2,4-D accounts for its usage to control weeds in reduced-tillage fallow for soil conservation. MCPA is the only highly effective herbicide to control wild mustard, a major weed problem in flax. Phenoxy herbicides are important components of mixtures for broad-spectrum weed control and for weed resistance management.

Data on phenoxy herbicide usage, losses from cancellation of registration of either 2,4-D or all phenoxy herbicides, alternative herbicides or weed control practices, changes in crop production, and major need for retaining phenoxy herbicides was obtained by contacting weed scientists or crop production specialists in each state and Puerto Rico. The original information was obtained through a mail response with telephone follow-up and assessment team contacts with specialists in an attempt for complete coverage of crop acreage. When coverage was not complete, data were extrapolated to represent 100% of the reported crop acreage. The extrapolation was less than 1% for all crop acreage; except seed crops and green pea, which was increased 25% to represent 100% of the acreage and; dry peas, which was increased 52%.

PHENOXY HERBICIDE REGISTRATION SUMMARY

Phenoxy herbicides registered for use in flax, grass and seed crops, pea, and fallow with use rates for various crops and production practices are presented in Table 1. The rate range presented represents differences in use depending upon the weeds present, time of application, and specific formulations.

LOSSES FROM BROADLEAF WEEDS

Losses from weeds vary greatly with the weed species, crop, environment, and weed infestation level. Research information is limited for losses from weeds in these crops. Wild mustard or common lambsquarters in flax (1) and texasweed in rice (present survey) can completely devastate the crops. Grass and alfalfa seed with excessive weed seed cannot be sold as certified seed and may not be saleable because of buyers' concern of acquiring new weed infestations. Furthermore, weeds in grass seed crops directly reduce seed yields.

Flax. Flax is a poor competitor with weeds and production would be discontinued by some growers without MCPA for the control of wild mustard, common lambsquarters, and various other broadleaf weeds. A dense infestation of almost any broadleaf weed can completely eliminate flax seed yield or prevent harvesting. Flaxseed yield loss from various weeds at various densities averaged 35% for 61 experiments (1).

Millet. Millet is moderately competitive to weeds because of its late seeding date, high seeding rate, and rapid growth. Millet is often seeded late after early flushes of weeds are controlled by tillage. However, weeds that germinate with these higher temperatures (e.g., redroot pigweed and sunflower) would still occur and cause production losses. Early season tillage followed by millet seeding is used in place of fallow to control weeds in some weed management programs. Thus, using herbicides in millet to prevent weeds from producing seeds to infest the field may be as important as using herbicides to prevent losses in millet production.

Rice. Broadleaf weeds in rice cause losses dependent upon the weed species or density as well as the vigor of the rice crop. Several respondents indicated that 2,4-D was required as a "salvation treatment" to control texasweed. Ducksalad, a short weed, was reported to reduce rice yield 21% and hemp sesbania, a tall weed, 40%, and both species are controlled by 2,4-D (8). In addition to direct yield losses from broadleaf weeds in rice, weeds interfere with harvest efficiency and lower the quality of the harvested rice.

Wildrice. Weeds can markedly reduce the yields of wildrice. However, growers use flooding and crop rotation in addition to 2,4-D to control weeds in wildrice. Common waterplantain, if not adequately controlled, can cause a complete loss in wildrice production. No alternative herbicides nor non-chemical weed control methods would be used if 2,4-D were lost to wildrice growers. The Minnesota respondent indicated that weed infestations would destroy 100% of the crop on the 10% of Minnesota wildrice acres currently being treated with 2,4-D. When all acres are included in the estimation, the resulting weighted average yield loss is 4.5%.

Seed crops. Weed seed contamination of grass or legume seed requires costly cleaning, and infestations of noxious weeds can prevent certification and make seed not saleable. In addition, uncontrolled weeds reduce seed yields, seed quality, and harvest efficiency.

Sugarcane. Broadleaf weeds in sugarcane are primarily a problem during crop establishment. Once sugarcane is established, the plants shade the soil and prevent further establishment of weeds. Losses from weeds in sugarcane were severe before the use of 2,4-D and other herbicides (6).

Dry pea. Reduction in yield from broadleaf weed interference was estimated to be 10% in Oregon and Washington (the major dry pea producing states), if the phenoxy herbicides were lost. The weighted average yield loss estimate was calculated as 2.5% for all dry pea acreage in the United States.

Green pea. If phenoxy herbicides were lost for use in green pea, broadleaf weed interference would lower yields 65% in California, 25% in New York and Wisconsin, 10% in Maine, and 4% in Washington. The weighted average yield loss was calculated as 5.6%.

Fallow. Weeds allowed to grow in fallow fields defeat the primary objective of fallowing, which is to conserve soil moisture. The second objective of fallow is to reduce the weed seed bank in the soil by preventing weeds from producing seed so that weed infestations are reduced in subsequent crops. Redroot pigweed, a common weed, produces 117,000 seeds per plant and many weeds produce more than 10,000 seeds per plant (9), indicating the importance of effective weed control to reduce the seed rain.

CURRENT WEED CONTROL METHODS

Flax. Weed control in flax involves trifluralin as a fall-applied preplant-soil-incorporated treatment, which controls grass weeds and some small seeded broadleaf weeds. MCPA or bromoxynil applied postemergence is used for control of various broadleaf weeds, e.g., wild mustard, common lambsquarters, Russian thistle, and wild buckwheat. Sethoxydim is used to control grass weeds. Delayed seeding of flax to accommodate several pre-seeding tillages to control early flushes of weeds was practiced prior to the availability of herbicides. However, flax yield was decreased by 0.28 bu/A for each day delay in seeding after May 1 in North Dakota (3). The phenoxy herbicide, MCPA, is used extensively in flax production. Approximately 39% of the 273,000 average acres in flax production in 1989 to 1991 were treated with MCPA or 107,000 acres (Table 2). About 40% of the flax acreage is treated in Minnesota, 39% in North Dakota, and 50% in South Dakota. The four responding states (Minnesota, Montana, North Dakota, and South Dakota) represented 100% of flax acres in the United States during those years. About 27,000 pounds of MCPA are used in any particular year for weed control in flax production at a cost of $98,000.

Millet. Millet usually is seeded later in the growing season when temperatures are warm, which facilitates rapid millet growth. ThThis helps reduce weed growth, but certain broadleaf weeds, e.g., redroot pigweed, also respond well to these conditions. Hence, 2,4-D is commonly used for control of redroot pigweed and other broadleaf weeds in millet. Dicamba is also registered for use in millet, but it is not used extensively. Many important broadleaf weeds, such as redroot pigweed, common lambsquarters, Russian thistle, and sunflower are controlled by 2,4-D in millet. Approximately 290,000 acres of millet were grown in 1987, the last year for which complete national acreage data are availabl(Table 2). Responses were received from seven states, which represented virtually all millet acreage in the United States. Colorado, Nebraska, South Dakota, and North Dakota are the major millet producing states. About 18%, or 52,000 acres were treated with 2,4-D, ranging from 40% in North Dakota to 5% in Wyoming, with 20% in Minnesota and Nebraska, and 9% in

Colorado. About 28,000 pounds of 2,4-D is applied yearly to millet at a rate of 0.54 lb/A for an estimated cost of $75,000.

Rice. Various practices are used to control weeds in rice, including crop rotation, timely seeding, water management, and tillage. Each practice influences the type of weed present. Aquatic broadleaf weeds in rice are mainly controlled by 2,4-D. Other herbicides for broadleaf weed control in rice are aciflurofen, bentazon, and bensulfuron.

The most effective herbicide for controlling many aquatic weeds such as ducksalad, redstem, texasweed, and gooseweed in rice is 2,4-D. Approximately 544,000 acres of rice were reported treated with phenoxy herbicides in seven rice producing states (Table 2). Weed scientists from five states responded to the survey, and phenoxy herbicide use in two additional states was added using assessment team estimates. These seven states represent 100% of average United States rice acres planted during 1989 to 1991. About 19% of the 2.9 million rice acres in these states was treated with phenoxy herbicides; 18.5% with 2,4-D and 0.5% with MCPA. Percent of acres treated varied considerably by state with Louisiana reporting 45% of rice acres receiving one annual treatment, Arkansas 20%, Florida 10%, California 7.5%, Texas and Missouri each 3%, and Mississippi 1%. An estimated 530,000 pounds of 2,4-D are applied annually at an average rate of 1 lb/A for an expenditure of $1.7 million.

Wildrice. Weeds are controlled in wildrice using a combination of crop rotations, flooding, and spot treatment with 2,4-D. Common waterplantain is an important weed controlled with 2,4-D. Wildrice fields are kept in rice for only 1 or 2 years to allow subsequent tillage for weed control. Fields are flooded early in the growing season 10 to 14 inches deep, which controls most weeds. Fall flooding is also used occasionally to supplement spring flooding. However, fall flooding is not desirable because ice can damage dikes. Wildrice production requires 2,4-D to supplement the above practices or for use when flooding is not possible because of an inadequate water supply.

About 28,000 acres of wildrice are grown in the United States, principally in Minnesota (19,000 acres or 69% of the total) and in California (8700 acres) (Table 2). Only in Minnesota is 2,4-D used in wildrice production. About 10% of Minnesota acreage is treated with 480 pounds of 2,4-D or about 0.25 lb/A per year. Treated acres represent 6.8% of acreage nationwide. Expenditure on 2,4-D is estimated to be $1500.

Seed crops. Grasses grown for seed are often grown in rows with cultivation between the rows for weed control. In addition to 2,4-D, other herbicides used for postemergence broadleaf weed control are bromoxynil, clopyralid, and dicamba. Diuron is used as a preemergence treatment in established grass stands. In alfalfa seed production, 2,4-DB is the only herbicide used for postemergence broadleaf weed control. One grower in North Dakota stressed the importance of 2,4-D for field bindweed control in alfalfa seed production.

Grass and legume seed is produced in various states, and 2,4-D is used to control broadleaf weeds in grass seed crops, and 2,4-DB is used in legume seed production. Weed control is essential to the production of pure seed required for sale of certified seed. However, phenoxy herbicide usage information is limited.

About 1.73 million acres are in seed crops (Table 2). Responses to the survey represented 1.3 million acres of seed crops in 10 states and an additional 374,000 acres in nine states was estimated by assessment team members. The combined acreage represents 96% of total seed crops nationally. Extrapolation was used to bring represented acres to 100%. Seed production includes alfalfa, Kentucky bluegrass, crownvetch, red clover, fescue, ryegrass, timothy, and birdsfoot trefoil. Large use of 2,4-D occurs in Minnesota Kentucky bluegrass production where 80% of the acreage is treated, North Dakota where 90% of the crop receives a 2,4-D application, Montana with 40%, and Oregon where 34% of the acres are treated with a combination of 2,4-D and MCPA. Overall, about 327,000 seed acres or 19% were treated with about 231,000 pounds of phenoxy herbicides: 2,4-D (193,000 pounds on 265,000 acres at 0.73 lb/A), MCPA (17,000 pounds on 34,000 acres at 0.50 lb/A), or 2,4-DB (about 21,000 pounds on 29,000 acres at 0.72 lb/A).

Sugarcane. Several herbicides are available for preemergence or for directed postemergence weed control in sugarcane. However, only dicamba is available as a postemergence alternative to 2However, only dicamba is available as a postemergence alternative to 2,4-D for broadleaf weed control. Dicamba was reported

Sugarcane is grown on 855,000 acres in the United States and Puerto Rico (Table 2). Extensive use is made of 2,4-D for weed control in sugarcane production. Fully 95% of Hawaii's 78,000 acres receives at least one treatment of 2,4-D yearly. About 80% of Puerto Rican acreage is treated with 2,4-D, 60% in Louisiana, and 20% in Florida. Responding states represented 100% of sugarcane acreage nationwide from 1989 to 1991. Overall, approximately 41% or 347,000 acres of the 855,000 acres in sugarcane receive about 923,000 pounds of 2,4-D or an average of 2.7 lb/A each year at an annual cost of $3 million. Normal use rate varies from 0.75 to 2 lb/A, but in some states multiple applications are made in one year. Dicamba is used in combination with 2,4-D for broadleaf weed control in Puerto Rico, and information on usage of mixtures in other areas is limited.

Dry pea and green pea. Various preemergence and postemergence herbicides, in addition to MCPA and MCPB, are registered for weed control in peas. Glyphosate and paraquat may be used for preplant control of emerged weeds; metolachlor, triallate, trifluralin, ethalfuralin, and metribuzin for preemergence weed control; sethoxydim for postemergence control of grass weeds; and bentazon for postemergence control of certain broadleaf weeds. MCPA and MCPB are the most effective herbicides for many of the broadleaf weeds found in pea. For example, common lambsquarter and Canada thistle are controlled better by MCPA or MCPB than by bentazon.

Fallow. Tillage has been the classical method of weed control in fallow, and it is still being used. However, most farm operators have substituted herbicides for at least some of the tillages in order to preserve the previous crop residual for erosion control. Cyanazine is available as a premergence treatment for fallow, but performance has been variable because of lack of rain in the areas using fallow for moisture conservation. However, cyanazine will not be available after year 2002 because in August 1995 Dupont and EPA personnel agreed to phase out cyanazine. Dicamba is available for fallow, but it is less effective than 2,4-D for controlling Russian thistle, an important weed in areas where fallowing is practiced. Both 2,4-D and dicamba are usually components of tank mixtures with glyphosate or paraquat for control of most grass and broadleaf weeds in fallow.

About 72 million acres are in fallow annually in the United States (Table 2). Glyphosate is used in combination with 2,4-D for broad-spectrum weed control as part of no-till fallow or as a supplement to conventional fallow. The use of herbicides to control weeds in fallow has increased greatly in recent years and has helped retain plant residue on the soil surface for erosion control. Land in fallow is extensively treated with 2,4-D. An estimated 20% of the 72 million acres yearly in fallow were treated at least once annually with 2,4-D. Approximately 7.2 million pounds of 2,4-D is applied to 14.6 million acres at 0.5 lb/A. Use is exceptionally extensive in Kansas where a reported 70% of fallow acres are treated, representing 6.2 million treated acres and 3.1 million pounds of 2,4-D. Other states with relatively extensive use of 2,4-D are New Mexico (50% of the fallow acres treated), Utah (35%), Oregon and South Dakota (30%), and Colorado (23%).

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COST OF CONTROL METHODS

MCPA costs about $3.65/lb and 2,4-D costs about $3.20/lb, making them the lowest priced herbicides and the lowest priced treatments for solving many broadleaf weed problems. Other herbicides with potential usage in these crops are 2,4-DB costing about $18.43/lb, bromoxynil $26.55/lb, dicamba $19.48/lb, cyanazine $5.95/lb, and clopyralid $152.9/lb. The price per pound is only given as a reference as use rate of each herbicide differs with the weed problem and the crop. Herbicides in a formulated mixture sometimes are less costly than the individual components because of marketing programs.

Delayed seeding of crops to control one or more flushes of weeds requires extra tillage at a cost of $3.80/A for each field cultivation (5). The delay in seeding may cause a direct yield reduction because of yield loss with later crop establishment. Farmers already use crop rotations, seedbed preparation, and seeding times to maximize weed control and crop yield.

ALTERNATIVES AND IMPACT OF THE LOSS OF EITHER 2,4-D OR ALL PHENOXY HERBICIDES

Millet, sugarcane, wildrice, and fallow would be impacted from the loss of all phenoxy herbicides the same as if only 2,4-D was lost, because 2,4-D is the only phenoxy herbicide registered for these crops. However, MCPA is the only phenoxy registered for flax, and MCPA and 2,4-DB are both registered for legume seed production. Thus, the loss of all phenoxy herbicides would increase losses for rice and grass seed production more than just the loss of 2,4-D.

Flax. The loss of 2,4-D would not influence flax production as it is not used because of potential injury to the flax. However, MCPA is an important herbicide in flax. Yield loss estimates are 10% of the value of the crop in Minnesota and 20% in North Dakota, whereas South Dakota growers may experience only a 2% loss in yield without MCPA. The weighted average yield loss estimate is calculated as 6.7% representing a loss in gross product value of $1.12 million.

The loss of MCPA would cause growers to convert to the use of bromoxynil on a significant portion of the acres previously treated with MCPA, although other methods of weed suppression and control also would be used. An estimated 80% of Minnesota acres would have one application of bromoxynil, as would 55% of North Dakota acres and 75% of acreage in South Dakota. A total of 16,000 pounds of bromoxynil would be used as an alternative chemical control method. Growers of flax in Minnesota would convert 20% and in North Dakota 25% of currently treated flax acres to production of another crop. Furthermore, delayed seeding and preemergence tillage would be used on 20% of previously treated North Dakota flaxes acres. An estimated $104,000 would be spent annually on non-chemical weed control methods. Many growers would discontinue growing flax without MCPA as the added cost, lower yield, and reduction in wild mustard control would eliminate profitability.

The estimated yield loss of 6.7% would result in an increase in farm level flax price of 6.9%, based on price elasticity of -0.9795(4). The subsequent loss in consumer surplus would be about $1.12 million while cost of production on treated acres would increase by $426,000 or almost $4.00/A (Table 3). Net revenue would decrease by $480,000 with a loss of $4.18/A on treated acres while growers with untreated acreage would realize a net $4.23/A increase in return. The net societal effect considering the loss in both producer and consumer surplus is a loss of $1.6 million, if MCPA (the only phenoxy herbicide used in flax) were banned (Figure 1).

Millet. If 2,4-D were no longer available, the alternative herbicide of choice would be dicamba, though much acreage would go untreated. Kansas, Minnesota, and South Dakota respondents indicated no alternative weed control methods would be used on millet acres if 2,4-D were lost. Similarly, an estimated 40% of acreage in both Nebraska and North Dakota would go untreated. As a result, dicamba use is estimated to total about 1,900 pounds at a cost of $29,000. Non-chemical methods were reported by Nebraska as a possible alternative on 40% of its millet acres at an estimated annual cost of $28,000.

A projected 1.8% reduction in millet production without 2,4-D would increase farm-level millet price 1.8%. Millet produced in the United States is used domestically as commercial bird or animal food, and a small portion is exported in some years to Japan where it is milled into flour for human consumption. This price increase would decrease consumer surplus by $560,000 while prothe United States is used domestically as commercial bird or anima(Table 3). Net farm revenue would decrease by about $27,000 or $0.54 per treated acre, but revenue from untreated acres would increase by $1.95. The loss of 2,4-D for weed control in millet would cause a net societal loss of $588,000 (Figure 1). The only phenoxy herbicide used in millet is 2,4-D so the economic impact would be the same if all phenoxy herbicides were lost.

Rice. If 2,4-D were no longer available for use in the production of rice, growers would convert to triclopyr on 38% of acreage previously treated with 2,4-D, propanil on 26%, bentazon on 17%, MCPA on 11%, acifluorofen on 5%, and other herbicides or nothing on the remaining 3%. Total alternative herbicides used was estimated as 315,000 pounds at an expenditure of $3.3 million. If all phenoxy herbicides were banned, 43% of acres previously treated with 2,4-D would receive triclopyr, 29% propanil, 19% bentazon, 6% acifluorfen, and the remaining 3% none or other herbicides. Estimated use of alternative herbicides with loss of all phenoxy herbicides would be 284,000 pounds at an expenditure of $3.25 million. An estimated 15% of rice acres previously treated with phenoxy herbicides in Louisiana would go untreated, as would 100% of Florida acres. No non-chemical alternatives were thought currently viable in rice production by survey respondents.

The loss of phenoxy herbicides for weed control in rice would reduce consumer surplus an estimated $15.4 million assuming a weighted yield loss of 0.5% and a 1.5% increase in farm price for rice based on a -0.32 price elasticity. Production costs would increase by $1.13 million or $2.07 per treated acre (Table 3). Net revenue would increase by $8.7 million as the value of production would more than offset the estimated yield loss. Net returns for treated acres would increase by $1.36/A and for untreated acres by $5.40/A. The net societal effect of a phenoxy herbicide ban would be a loss of $6.7 million (Figure 1). The loss would be essentially the same with non-availability of either 2,4-D or all phenoxy herbicides because MCPA only accounted for 0.4% of the phenoxy usage.

Wildrice. No alternative chemical materials or non-chemical weed control methods would be used if 2,4-D were lost to wildrice growers. Weed infestations would destroy all of the crop on the 10% of total Minnesota wildrice acres that are currently treated with 2,4-D. The loss of 2,4-D would cause a weighted average of 4.5% wildrice yield loss, a 14% increase in farm-level wildrice price, leading to an increased cost to consumers of about $2.9 million. Production costs would decrease by the amount formerly spent to purchase 2,4-D, $1500 or a decrease of $0.80/A, as no alternative weed control would be used (Table 3). Net revenues to growers would increase by about $1.9 million or about $67 per treated acre and $105 on untreated acres. The overall net societal effect of a loss of 2,4-D in wildrice production would be a loss of $1 million (Figure 1).

Seed crops. The only phenoxy herbicide of importance for use in legume seed production is 2,4-DB. Alternatives to phenoxy herbicides in grass seed production are dicamba, bromoxynil, and clopyralid for postemergence broadleaf weed control. Considering all seed crops, 15.3% of the acres are treated with 2,4-D, 2.0% with MCPA, and 1.7% with 2,4-DB.

The cancellation of 2,4-D, leaving other phenoxy herbicides available, would cause grass seed growers to use MCPA on up to 80% of grass seed acres that are currently treated with 2,4-D. Bromoxynil and dicamba would be applied to 8% and 5% of acres formerly treated with 2,4-D in grass seed production. Costs of herbicide control would increase to $3.7 million from the current $1.1 million being spent for all phenoxy herbicides.

If all phenoxy herbicides were lost to grass seed growers, the herbicides of choice would be bromoxynil (projected to be used on 47% of current phenoxy herbicide treated acres), dicamba (32%), and clopyralid (18%). Expenditures would drop to $2.7 million as it is expected that large acreages in a number of states would go untreated including Kentucky bluegrass seed produced in Minnesota (55%), North Dakota (10%), and South Dakota (20%). Non-chemical weed control methods, consisting principally of tillage and cultivation, would be used in Missouri, Montana, and North Dakota at an estimated cost of $123,000.

If 2,4-D was lost, production costs would increase by about $2.2 million or $7.14/A on acres currently treated with phenoxy herbicides (Table 3). Net revenue would decrease by $5.7 million, which combines the effects of the increase in costs and projected decrease in output. Returns on treated acres would decline by $9.90/A while no change in net revenue would occur on untreated acres. The overall net societal loss if all phenoxy herbicides were not available for seed crops is $5.7 million (Figure 1).

Sugarcane. Alternatives to 2,4-D in sugarcane production are paraquat, dicamba, glyphosate, atrazine, ametryne, diuron, and metribuzin. About 842,000 pounds of substitute herbicides comprised of 735,000 pounds of atrazine and 100,000 pounds of dicamba would be used in sugarcane production if 2,4-D were lost. Net herbicide costs would decrease to approximately $1.7 million, a drop of 43% relative to 2,4-D expenditures. In certain states, however, costs of weed control would increase significantly. For instance, in Hawaii projected costs for herbicides would increase from $356,000 presently spent on 2,4-D to $3.5 million, about equally split between atrazine and dicamba. This is offset by expenditure projections in which no substitute materials or methods are expected to be used for weed control. For example, expenditures for herbicides in Louisiana are expected to drop from $2.3 million to $1 million as 60% of the acres would go untreated.

Few non-chemical alternatives are expected to be used if 2,4-D were lost for weed control in sugarcane. Commodity experts in Puerto Rico predict growers would cultivate for weed control on about 40% of acreage currently treated with 2,4-D. Florida growers would use alternative weed control methods if 2,4-D were no longer available.

Yield loss projections are significant and range from 5% of crop value in Hawaii to 20% crop loss in both Florida and Puerto Rico. Overall weighted average yield loss is projected as 5.7%. Alternative weed control costs would total $1.7 million, or $4.81/A (Table 3), including the costs of non-chemical methods.

There exist few price response studies estimating price elasticity of demand information for sugarcane. Using estimates for "sugar" or "sweeteners" is inappropriate because of the number of substitute commodities used in the manufacture of sweeteners. Sugarcane is only one possible ingredient in the manufacture of sugar, there being substitutes, including corn sweeteners and sugar from sugar beet, therefore its elasticity measure would be much more elastic than that for sugar itself. Thus, a perfectly elastic demand curve was assumed.

Loss estimates may be overestimated since the price effects of diminished sugarcane sugar are not included in the calculations. The loss of 2,4-D would decrease net revenue $51.1 million with returns from fields currently treated with 2,4-D declining $62.60/A. The loss of all phenoxy herbicides would not change the loss because only 2,4-D is registered for sugarcane. Many of the weed control alternatives require preemergence application, precise timing of treatment, or directed applications. The overall net societal effect of a phenoxy herbicide ban in sugarcane production would be a loss of $51.1 million (Figure 1).

Dry pea. The loss of 2,4-D would have no effect on dry pea production, as it is not used in that crop. If the phenoxy herbicides, MCPA and MCPB, were lost to dry pea growers, chemical alternative would include bentazon, imazethapyr, and metribuzin although not in significant amounts. Estimates indicated that only about 1,700 pounds of these herbicides, 87% of which would be bentazon, would be used. In Washington, respondents indicated that 80% of the currently treated acres would not receive any weed control treatments, 5% would be converted to production of another crop and 5% would be handweeded at an estimated aggregate cost of $22,000.

The weighted average yield loss from a ban on the phenoxy herbicides, MCPA and MCPB, was 2.5% (Table 3). Economic analysis indicated that this reduction in yield would result in a loss to the consumer because of a price increase for the commodity, and the growers would gain revenue from the increased price. The effect, considering the gain in producer surplus and the loss in consumer surplus, was estimated as a net societal loss of $600,000 (Figure 1).

Green pea. The loss of 2,4-D would have no effect on green pea production, as it is not used in that crop. If MCPA and MCPB were lost, growers would be expected to use alternative herbicides on some of the acres currently being treated with those phenoxy herbicides. It was estimated that the 79,000 pounds of MCPA and MCPB currently used annually (Table 2) would be replaced by about 61,000 pounds of alterative herbicides. Chemicals of choice would include bentazon (37,000 pounds), glyphosate (21,500), trifluralin (2,100 pounds), and imazethapyr (440 pounds). Respondents in New York state and Wisconsin expect that no substitute weed control methods would be used in their states if phenoxy herbicides were lost. The respondent from Maine indicated that 78% of acres currently treated with phenoxy herbicides would be cultivated at a cost of about $10,000. Current expenditure for weed control on MCPA treated acres in Maine is $2,400.

If MCPA and MCPB were banned, yield losses were expected to be significant for a number of states. Yields were expected to decrease by 65% in California, 25% in New York and Wisconsin, 10% in Maine, and 4% in Washington. The weighted average yield loss estimate was calculated as 5.6% (Table 3). Economic analysis indicated that this reduction in yield would cause an increased price to the consumer. Growers' costs of production would increase, but these would be more than offset by increased revenue from increased price of the commodity. The net societal effect considering the changes in producer and consumer surplus values is estimated as a net loss of $8 million (Figure 1).

Fallow. Herbicide alternatives of choice, if 2,4-D were not longer available, include glyphosate, which is projected to be used on 70% of currently treated acres and dicamba on 22%. Herbicide use would decrease from 7.2 million pounds of 2,4-D to a total of 5.7 million pounds of alternatives, which are used at lower rates. Costs of chemical control would increase, however, from a total of $22.9 million currently being spent on 2,4-D to about $115 million. Non-chemical weed control methods, including tillage and mowing, would also be used extensively. Total estimated increase in expenditures for non-chemical weed control methods is $40.3 million.

Many respondent suggested yield losses would occur if 2,4-D were canceled for weed control on fallow land. These included estimates of 20% in Kansas and New Mexico; 10% in Montana, Oregon, and Utah; and 3% in both North Dakota and South Dakota. The estimated yield losses are because of uncontrolled weeds using moisture that could have been used by the following crop, and because of increased weeds in the following crop from uncontrolled weeds producing seed in the fallow year. An aggregate yield loss estimate was not calculated for fallow as there is no specific crop and therefore no associated crop value to be discounted. Therefore the only effect of a cancellation of 2,4-D for use in fallow that can be estimated is simply the cost of alternative chemical and non-chemical weed control, which is estimated at about $132 million or an increase in cost of $9.08 per treated acre (Table 3). The loss would be the same if all phenoxy herbicides were not available as only 2,4-D is used in fallow.

COMPELLING REASONS TO RETAIN PHENOXY HERBICIDES

The phenoxy herbicides are often essential for continued production of crops having low economic return and for reduced tillage, soil conserving, crop production. The availability of phenoxy herbicides is important for many crops and crop uses to provide alternatives for weed control management and weed resistance management.

Flax

1. Loss of MCPA for flax would leave only bromoxynil as an alternative postemergence broadleaf control herbicide.

2. MCPA is the most effective and economical treatment for wild mustard control in flax.

3. Flax would be lost for many growers as a rotational alternate crop because reduced weed control and increased cost of alternative measures could eliminate profitability.

4. A monoculture of small grains would increase in the area flax is grown presently because of limited adapted crops.

Millet

1. Loss of 2,4-D would leave only dicamba as an alternate postemergence herbicide for weed control in millet.

2. Millet would lose its advantage as a weed controlling alternate rotational crop as many millet acres would be left untreated if 2,4-D was lost.

3. Alternative, dicamba, would be considered too costly for use in millet.

4. Soil eroding fallow would increase without the advantage of millet as an alternative crop.

Rice

1. Late season control of texasweed in rice requires 2,4-D.

2. Control of weeds on rice field levees requires 2,4-D as part of a weed management program.

3. A wider spectrum of aquatic weeds are controlled by 2,4-D than by alternatives.

4. Rice quality is improved by use of 2,4-D which reduces weed seed contamination.

5. The increased cost of possible alternatives for 2,4-D in rice would equal a 3 to 4 bu/A yield loss.

Wildrice

1. The only herbicide available for weed control in wildrice is 2,4-D.

2. Waterplantain, a devastating weed in wildrice, is only controlled by 2,4-D as part of an integrated flooding and rotation program.

Seed crops

1. The least costly treatments for control of many broadleaf weeds in grass seed production are 2,4-D and MCPA.

2. Efficient weed control in grass seed crops requires 2,4-D and MCPA for use in mixtures with other herbicides for broad-spectrum weed control.

3. Control of all weeds in seed production is essential for seed certification for preventing spread of weeds.

4. The only highly selective postemergence herbicide for weed control in legume seed production is 2,4-DB.

Sugarcane

1. In sugarcane production, 2,4-D is important in combination with dicamba for broad-spectrum broadleaf weed control in Puerto Rico.

2. In sugarcane production, 2,4-D provides an important alternative herbicide for weed control.

Pea

1. MCPA and MCPB provide less costly weed control than would alternative methods of control.

2. Decreased pea yields from loss of MCPA and MCPB would cause increases in costs to the consumer.

Fallow

1. Alone or in mixture with other herbicides, 2,4-D is required for low cost broadleaf weed control in reduced-tillage fallow.

2. The low cost of 2,4-D is essential to soil conserving reduced-tillage fallow because of low productivity of these dry areas that must be fallowed.

RESISTANCE MANAGEMENT

The loss of the phenoxy herbicides, particularly 2,4-D, would greatly reduce postemergence options for broadleaf weed control. Weeds not controlled by the alternatives, especially broadleaf perennials, would increase, and the potential for resistant weeds to develop would increase.

WEED MANAGEMENT OPTIONS

In most of the production practices discussed in this chapter, the loss of the phenoxy herbicides would eliminate the primary postemergence herbicide treatment for broadleaf weed control. Depending on the crop, bromoxynil, dicamba, and clopyralid are registered, but these usually are used in mixtures with a phenoxy herbicide. The mixtures reduce the total amount of herbicide used and increase the weed control spectrum. Furthermore, the loss of the phenoxy herbicides would in many cases lead to increased use of preemergence herbicides, which are applied without knowledge of the weed infestation that will later occur. This would be contrary to good integrated pest management (IPM) practice. Efficient weed management depends on the availability of herbicides effective on different weeds to minimize amounts used according to the species present. Rotations of crops with different growth characteristics are important to weed management systems (2, 7). Without phenoxy herbicides for wild mustard control, flax, and possibly millet would not be grown by many farmers.

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Table 1. Rates of phenoxy herbicides currently registered for various uses in the United States.

Crop or use	Phenoxy herbicide 2,4-D	MCPA	2,4-DB	MCPB
	lb/A			
Flax	----[b]	0.12 to 0.25	----	----
Millet	0.25 to 0.5	----	----	----
Rice	0.25 to 1.25	0.5 to 1.25	----	----
Wildrice	0.25	----	----	----
Grass seed	0.5 to 2	0.5 to 1.5	----	----
Alfalfa and other legume seed	----	0.125 to 0.25[a]	0.5 to 1.5	----
Sugarcane	0.75 to 2	----	----	----
Pea (dry and green)	----	0.125 to 0.37	----	0.5 to 1.5
Fallow	0.5 to 3	----	----	----

[a] Both the amine and sodium salt are registered for legumes underseeded in small grains.
[b] The herbicide is not registered on this crop.

Table 2 Yearly production, price, and phenoxy herbicide use for various crops and fallow in the United States and Puerto Rico.

Crop[a] and herbicide	Acres in production[b]	Production[b] and yield units	Price per unit	Phenoxy herbicide use[c] Acres treated		Pounds used	Use rate
		(000)	$	(000)	%	(000)	lb/A
Flax	273	3,709 bu	4.52				
MCPA				107	39.2	26.7	0.25
Millet	292	4,419 cwt	7.00				
2,4-D				52	17.8	28.0	0.54
Rice	2,859	171,600 cwt	6.47				
2,4-D				530	18.5	530.0	1.00
MCPA				14	0.5	14.0	1.00
Wildrice	28	16,380 lb	1.68				
2,4-D				2	6.8	0.5	0.25
Seed crops	1,730	475,512 lb	0.87[d]				
2,4-D				265	15.3	193.0	0.73
MCPA				34	2.0	17.0	0.50
2,4-DB				29	1.7	21.0	0.72
Sugarcane	855	29,405 ton	29.74				
2,4-D				347	40.6	922.9	2.70
Dry pea	233	389,100 lb	0.07				
MCPA or MCPB				57	24.4	12.9	0.23
Green Pea	330	474 ton	259.00				
MCPA or MCPB				102	31.0	79.0	0.77
Fallow	72,000	----[e]	----				
2,4-D				14,598	20.3	7,210.0	0.50
Total	78,600	-----	----	16,137	20.6	9,055.0	----

[a] For purposes of this table, fallow is considered a crop.

[b] Average for 1989 to 1991 for flax, rice, wildrice, green pea, and sugarcane; for 1987 for millet, seed crops, dry pea, and fallow.

[c] Based on 1993 survey of 1992 data.

[d] Average of alfalfa seed and grass seed crops.

[e] Not applicable.

Table 3. Estimated changes in production and in cost of production of various crops and fallow in the United States and Puerto Rico with the loss of either 2,4-D or all phenoxy herbicides.

	Assuming loss of 2,4-D Loss of production				Assuming loss of all phenoxy herbicides Loss of production			
Crop[a]	Quantity and yield units	Percent	Cost change per treated acre[b]	Total cost change	Quantity and yield units	Percent	Cost change per treated acre[c]	Total cost change
	(000)	%	$	$ (000)	(000)	%	$	$ (000)
Flax[d]	0	0	0	0	250 bu	6.7	3.98	426.1
Millet[e]	79 cwt	1.8	0.55	28.2	79 cwt	1.8	0.55	28.2
Rice[f]	800 cwt	0.5	2.07	1,130.0	800 cwt	0.5	2.07	1,130.0
Wild rice[e]	557 lb	4.5	-0.80	-1.5	557 lb	4.5	-0.80	-1.5
Seed crops[g]	3,854 lb	1.0	7.14	2.2	3,854 lb	1.0	7.14	2.2
Dry pea [h]	0	0	0	0	9,728 lb	2.5	0.72	41.0
Green pea[h]	0	0	0	0	27 ton	5.6	7.86	800.0
Sugar cane[e]	1,662 ton	5.7	4.81	1,685.0	1,662 ton	5.7	4.81	1,685.0
Fallow[e]	---[i]	---	9.08	132,400.0	-----	---	9.08	132,400.0

[a] For purposes of this table, fallow is considered a crop.

[b] Refers to acres estimated to have been previously treated with 2,4-D.

[c] Refers to acres estimated to have been previously treated with any phenoxy herbicide.

[d] Only phenoxy herbicide involved was MCPA.

[e] Only phenoxy herbicide involved was 2,4-D.

[f] Virtually the only phenoxy herbicide involved was 2,4-D, slight useage of MCPA (shown in Table 2) has been omitted in this table.

[g] Most phenoxy herbicide involved was 2,4-D, but approximately 10% of the effects were attributable to MCPA and 9% to 2,4-DB. Effects of MCPA and 2,4-DB have not been separated from the effects of 2,4-D in this table.

[h] Both MCPA and MCPB involved, but their effects have not been separated in this table.

[i] Not applicable.

Chapter 10

Use of 2,4-D in Orchard, Vineyard, and Soft Fruit Production in the United States

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Abstract. The herbicide 2,4-D has been used for selective weed control in tree fruit, nut, grape, and soft fruit production for many years and is the only phenoxy herbicide used in these crops. It has also been used as a growth regulator in navel oranges and grapefruit to delay fruit drop. The principal use of 2,4-D is for selective postemergence control of annual and perennial broadleaf weeds in orchards and vineyards. It is applied over strawberry beds after harvest for broadleaf weed control. Total 2,4-D use in these crops is estimated at 379,000 pounds, used on 351,000 acres annually. If 2,4-D were banned, it is estimated that use of alternative products would increase herbicide use in these crops by 31,200 pounds annually. Postemergence applications of 2,4-D cost about $2.15 to $8.75/A depending upon the crop, as compared to $16 to $32/A for alternative, nonselective postemergence herbicides, or $30 to $65/A for preemergence herbicides. The estimated 1992 net societal loss, if 2,4-D were banned for weed control in these crops, is $111.3 million. The loss of 2,4-D as a growth regulator in navel orange and grapefruit production, would cause an $80 million annual loss. Weed resistance has not been a problem with 2,4-D use in these crops. To achieve integrated weed management (IPM) in these crops, 2,4-D has been used as a selective herbicide to control broadleaf weeds and to maintain grass cover crops. These programs also improve overall pest control in orchards and vineyards and reduce control costs and pest problems for the farmer.

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INTRODUCTION

Broadleaf weeds are widespread and common in orchards and vineyards. There are annual, biennial, and perennial broadleaf weeds. Annual weeds are easily controlled with herbicides, cultivation, mowing, or flaming, and there are more annual species than perennial species of weeds. However, weed shifts occur as weed escapes take the place of the controlled weed species. The major problem weeds in these crops are perennial species. Common broadleaf perennials such as field bindweed, common dandelion, common catsear, plantains, Russian knapweed, Canada thistle, hoary cress, asters, and woody brambles are all problems in orchards and vineyards. There are currently approximately 2.95 million acres of orchards and vineyards in the United States. The principal period of weed competition for vine or tree species is during the first 3 to 5 years following establishment (6). Once the crop is established, broadleaf weeds affect management practices, such as pruning for tree structure (10); irrigation amount and scheduling (5, 8); spraying for insects, mites (4), or plant pathogens; and harvest efficiency. In some instances the control of broadleaf weeds will decrease reservoirs of pathogen inoculum or sites for the buildup of insects that will damage the tree, vine, or fruit. Gophers, voles, and rabbits are troublesome where weeds provide them forage, seeds, and shelter within the orchard. Thus, 2,4-D is used as part of IPM programs to improve orchard floor management, thereby reducing overall pesticide use.

PHENOXY REGISTRATION SUMMARY

Registration of 2,4-D has been difficult in some orchard and vineyard crops due to their small acreage, lack of patent protection for the product, cost of registration, lack of support for re-registration, and the potential of losing money on litigation where a small amount of product is sold in an expensive crop if yield loss or crop damage was to occur. Currently, the 2,4-D amine (dimethylamine salt) formulation is registered in many crops including apple, pear, stone fruit, and nuts, but not in California. This formulation is not registered, however, in some tree crops (e.g., fig, olive, persimmon, pomegranate, quince, and citrus fruit), some of the soft fruits (e.g., cranberry), or some other minor crops such as kiwifruit or guava.

Another 2,4-D formulation (triethylamine salt) is registered in almond, apple, apricot, grape, nectarine, peach, pear, pecan, pistachio, plum, prune, and walnut in California, Washington, and Oregon and on filbert, as a sucker control agent, in Oregon. These products are registered for trees and vines that are more than 3 years of age for control of susceptible annual and perennial weeds. Other formulations and special local need labels may be available for state registrations in some crops.

The isopropyl ester of 2,4-D is registered as a plant growth regulator in navel orange and grapefruit. It is used on young fruit to reduce fruit drop. This has allowed longer harvest periods of high quality navel orange and grapefruit in Arizona and California. This is the only registration where 2,4-D is applied directly to the tree. The isopropyl ester formulation is not registered as a herbicide to control weeds on the grove floor.

BROADLEAF WEED LOSSES

Losses from broadleaf weeds alone have not been evaluated. Using best management practices, there is an estimated loss to all weeds in deciduous fruit, nut, and grape crops of $237.7 million and in orange, lemon, grapefruit, and tangerine of $119 million annually (3). A broad- spectrum of weeds in deciduous orchards have reduced tree growth up to 50% during the first through the third year of tree establishment (6). In deep soils, as trees mature there is less competition from weeds to the tree, but other losses such as decreased harvest efficiency, fire hazard, and management costs to control the weeds become more important. In poor soils, weed competition for water and nutrients remain a problem for all tree and vine crops regardless of age.

In total there are an estimated 379,000 pounds of 2,4-D used for selective broadleaf control in tree, vine, and soft fruit annually. This would give an approximate cost of production for broadleaf weed control of $956,200.

CURRENT CONTROL METHODS

Current control methods for broadleaf weeds vary by crop and location. The method of control will depend generally on the weed species and the desires of the grower. Many orchards are treated with herbicides in strips or bands within the tree row or vine row. The herbicide treatment may be a single preemergence material, a combination of preemergence materials, a combination of preemergence and postemergence materials, or postemergence materials only. The herbicides used are dictated by weed species, crop tolerance, soil type and texture, and irrigation method. Where paraquat or glyphosate is used in the strip, bare ground results, which opens the soil to erosion. In vineyards, weeds in the row are often controlled with a hoe-plow and between the rows with a disk. The hoe-plow is used once per season, but the disk may be used several times as weeds germinate or reinvade. Recently more in-row cultivators are being used in vineyards with minimal use in orchards. These cultivators are used one to four times during the growing season. There is a small use of organic mulches (straw, wood chips, or biomass grown between the rows and then placed in the row). Some small areas are growing a "living mulch" of annual or low-growing perennial plants in the row. If a grass cover is desired, 2,4-D may be used to selectively suppress or control the broadleaf weeds and maintain a grass cover. This type of selective treatment is used in Oregon for the control of dandelion and other perennial broadleaf weeds 1 out of 3 years As part of an IPM program, the loss of 2,4-D would be a major detriment to the ability of growers to manage weeds in their crops. Another selective use of 2,4-D is to use it in sites where clovers or a grass-clover mixture are a part of the vegetation on the orchard floor. Broadleaf weeds are controlled with only slight 2,4-D injury to the clovers, thus allowing them to survive in the orchard.

Currently there are several problems with specific weeds, which harbor diseases or insects, that would be affected by the loss of 2,4-D. Plantain species in California harbor rosy apple aphid that causes major problems in apple production. When buckhorn plantain or broadleaf plantain is controlled with 2,4-D, the apple aphid problem is reduced. Field bindweed is a major host for the two-spotted spider mite in pear orchards in Oregon, California, and Washington. With a timely application of 2,4-D, field bindweeof 2,4-D, field bindweed is reduced, thus reducing the buildup and invasion of mites. With an untimely mowing or disking, or even an untimely application of 2,4-D, the mites are often a problem in the pear tree (4). Dandelion and field bindweed often attract gophers who then feed in a vineyard or orchard. It has not been proven that gophers increase damage to the tree or vine, but when weeds are present the gopher populations are higher. Reducing these weed species and periodically cultivating, reduces the gopher population. Certain broadleaf weeds are better hosts for nematodes than are grasses, and in some instances some grasses will reduce c[2].

Apple and pear. Preemergence herbicides are used in apple and pear orchards, but the principal use of 2,4-D is for selective control of broadleaf weeds while leaving a grass cover, or reduce perennial weeds such as field bindweed, dandelion, catsear, or hawksbeards. Loss of 2,4-D would lead to additional use of glyphosate (up to 100% of currently 2,4-D treated acreage in some crops), and lesser amounts of paraquat (from none to 94% in various crops). There should be concern with increased dependency on glyphosate as one of the few postemergence herbicides in apple and pear orchards because we cannot rotate crops easily, and there are few new herbicides to alternate with glyphosate to reduce the chance of developing herbicide resistant weeds. Because one of the preemergence herbicides (terbacil) that will control annual and perennial broadleaf weeds in apple has been dropped and a second material (dichlobenil) is expensive and unreliable for weed control without some herbicide damage, there are few alternative options for selective herbicides for the control of broadleaf weeds. Respondents in many states predicted increased use of mowing for weed control if 2,4-D were banned. This would mean an increased use of fossil fuel and a potential increased hazard of working with farm equipment by increasing mowing two or more times instead of a single 2,4-D application. There is also potential injury to trees when equipment is operated close to the tree. Loss of 2,4-D as a selective material would also limit options of growers for cover crops in apple or pear orchards.

2Personal communication. 1995. M. McHenry, Ext. Nematologist, Univ. California, Parlier, CA.

Apricot, cherry, coffee, peach, nectarine, plum, and prune. These crops usually are hand harvested, but some are shaken onto catching frames. Tall weeds such as horseweed, fleabane, annual sowthistle, and common cocklebur interfere with workers at harvest. Broadleaf weeds must be controlled early before "hanger" limbs on peach or nectarine trees grow low enough to be contacted by the herbicide. This is more of a concern with the potential 2,4-D substitute, glyphosate. Glyphosate has given considerable injury to peach and nectarine, even when it has been applied as a directed spray to the soil and base of the tree. Young trees are more susceptible to injury and drift onto the low leaves, and glyphosate causes more injury, such as trunk splitting, than 2,4-D. An application of 2,4-D in the spring will reduce broadleaf weeds such as mustards, which provides a habitat for green peach aphid to buildup and move onto potato and infect them with a virus.

Alternate methods of weed control were indicated for all states from which responses were received. Mowing to reduce weeds would increase, but there would be a weed shift to low-growing species and more particularly to perennials. If weeds cannot be removed around the base of the tree by hand weeding or by herbicides, tree life will be reduced and fruit quality will decline through the defacing of fruit by insects found in the weeds and trees. If field bindweed is present there is a potential for outbreaks of mites from the weeds remaining in the orchard, or cherry buckskin disease from the mountain leafhopper on broadleaf weeds such as curly dock and California burclover in cherry orchards in California[3].

[3] Personal communication. 1995. A.H. Purcell, Dep. Entomology, Univ. California, Berkeley, CA.

Coffee. Applications of 2,4-D are used in coffee in Puerto Rico for the control of broadleaf weeds, primarily in the tree row. Herbicides are generally applied in a strip within the row with the weeds growing between the tree rows being mowed.

An alternative herbicide, paraquat, is not selective for broadleaf weeds; so grasses cannot be maintained in the orchard if it is used. Another alternative could be glyphosate, but it is not as selective as 2,4-D to the coffee tree. There is a concern about dicamba being used as an alternative herbicide for 2,4-D in coffee, because it has soil persistence and can injure trees by root uptake, spray drift, or volatility.

Grape. The primary use for 2,4-D in grape vineyards is for the control of annual broadleaf weeds and susceptible perennial weeds. Some broadleaf weeds are not controlled with preemergence herbicides, and there would not be good alternatives for their control if 2,4-D were lost. Field bindweed, common St. Johnswort, and Russian knapweed could not be selectively controlled in annual or perennial grass sod in vineyards without 2,4-D.

Selective control of broadleaf weeds in vineyards gives the farmer the option to plant cover crops for erosion control or to decrease competition from weeds. It also allows the farmer options for herbicide or weed control methods in a cover-crop rotation with less chance of herbicide resistance developing.

Grapes are very sensitive to 2,4-D. Even at low rates 2,4-D can damage grapes if applied onto or drifted onto foliage or a fresh pruning wound. Grapes are most sensitive during or after flowering.

Alternative herbicides exist for many broadleaf weeds. The preemergence herbicides, diuron and simazine, will control most annual broadleaf weeds, but not all. Norflurazon, though used mostly for annual grass control, will also control some broadleaf weeds. Dichlobenil will control most annual broadleaf weeds and will suppress field bindweed. When used at rates that are effective on field bindweed, dichlobenil is marginally selective on established vines, but not safe on young vines. Trifluralin will also control field bindweed, but it requires special equipment and application methods. Cultivation equipment can be used to control most weeds, but not field bindweed. Cultivation eliminates the possibility of no-till culture of grapes, which is a desired method of managing vineyards by many farmers. In no-tilled grapes, 2,4-D can be used for the selective control of dandelion, a common weed in grass-mulched vineyards.

Strawberry. Broadleaf weeds can be controlled in strawberry with 2,4-D. In states where strawberry is used as a perennial crop (Pennsylvania, New York, Ohio, and other northern states) a major proportion (75% to 90%) of the strawberry acreage is treated with 2,4-D after harvest or at the end of the growing season. Removal of 2,4-D would be a major loss for selective control of broadleaf weeds in the crop. In California, 2,4-D is used primarily focrop (Pennsylvania, New York, Ohio, and other northern states) a major proportion (75% to 90%) of the strawberry acreage is treated with 2,4-D after harvest or at the end of the growing season. Removal of 2,4-D would be a major loss for selective control of broadleaf weeds in the crop. In California, 2,4-D is used primarily for the control of field bindweed in the alternate year of the annual strawberry

Few other herbicides are available for use in strawberry fields. Thus, if 2,4-D were lost, most of the weed control would be by mulching or hand weeding, which would increase production costs and reliance on transient labor. Strawberry damage often occurs with hand weeding and loss of stand would likely occur. If methyl bromide is banned by the year 2,000, as is currently the schedule, there will be an additional need for 2,4-D for broadleaf weed control in the California system of strawberry management.

Walnut and other nut crops. Persian (English) walnut, pecan, almond, and pistachio nuts are harvested from the ground after they fall naturally or after they are shaken mechanically off the tree. The orchard floor must be relatively free of vegetation, or physical interference with the harvesting operation will reduce recoverable yield of nuts. Broadleaf weeds such as common purslane, puncturevine, prostrate knotweed, and field bindweed are major problems during harvest. In these crops, 2,4-D is used over the total orchard floor rather than only in strips within the tree row. If 2,4-D were banned, there not only would be an estimated increase of 32% of total herbicide used, but part of this increase would involve herbicides currently under EPA review because of groundwater concerns.

Navel orange and grapefruit. The isopropyl ester of 2,4-D is applied as a growth regulator on navel orange and grapefruit from October or November at about 0.06 lb/A, or at 0.03 lb/A in December to January. This application prevents formation of the abscission layer in January so the fruit will not fall from the tree. The application of 2,4-D allows navel orange fruit to be harvested into June rather than only March or April. Application of 2,4-D is used on most of the 110,000 acres of navel orange in Arizona and California, and on about 70% of the 20,000 acres of grapefruit, at a cost of about $7.70/A.

IMPACT OF THE LOSS OF 2,4-D BY CROP

Almond. California grows almost 100% of the almond crop in the United States. The triethylamine salt of 2,4-D is registered in California and was used on about 62,100 acres (Table 3) or 15.5% of the 401,000 planted acres (Table 1). With the loss of 2,4-D, there would be an estimated increase of herbicide use by 31,100 pounds (Table 2) for an increased cost of $1.07 million (Table 4), or a net societal loss in 1992 of $1.07 million (Table 6).

Without 2,4-D, glyphosate would be increasingly used as a nonselective herbicide, on 75% of the acreage currently treated with 2,4-D (Table 5). This treatment would decrease the options of growers for maintaining a cover crop to decrease soil erosion, increase water penetration, and maintain the organic matter content of the soils. A shift away from 2,4-D would increase production costs to the grower and increase the chance of developing weed resistance to glyphosate.

Apple. Respondents in 22 states, representing most major apple producing regions, indicated that approximately one-quarter of the 379,000 reported acres is treated with 2,4-D for weed control (Table 1). These data were extrapolated to estimate 2,4-D use on all 601,000 acres of apples in the United States. About 154,000 acres are treated each year with an estimated 188,000 pounds of 2,4-D at an average rate of 1.2 lb/A (Table 3). If 2,4-D were lost to apple growers, most respondents indicated that weed control would be accomplished with both chemical and non-chemical alternatives. In Washington, the preeminent apple producing state, growers were expected to use paraquat and glyphosate, or a combination of herbicides, on just 20% of currently treated acreage; whereas, 50% of the acres would receive alternative weed control methods such as disking, cultivation, hand weeding, and mulching. Experts estimate that growers on 30% of currently treated acres in Washington would use no substitute methods for weed control. Control costs in Washington would increase from $246,000, the current expenditure for 77,000 pounds of 2,4-D, to $1,357,000, which includes approximately $245,000 for non-chemical weed control methods. The value of apple yield loss in Washington without 2,4-D was estimated at 5% of the crop. Nationally, yield of apples is expected to decline by 1.4% if 2,4-D were no longer available (Table 4). Grower expenditure for alternative chemical control would increase by $3.52 million or $22.88 for each acre previously treated with 2,4-D.

Alternative herbicide applications would total 140,000 pounds replacing the 188,000 pounds of 2,4-D currently in use. Glyphosate would be about 110,000 pounds of the total or 78%, and paraquat about 17,500 pounds or 13%, with simazine, dichlobenil, oryzalin, and napropamide used in much smaller amounts (Table 5).

Economic analysis of the apple market requires market segmentation into product directed for fresh market use and that consumed as processed apple products. Price elasticities of demand differ for each segment, as do prices received by farmers for the two differentiated products. In addition, it was assumed that the percentage of acres producing for each sector was equivalent to the percent of total output directed to that sector. That is, 43% of total apple acres produced for the processing sector, and 57% for the fresh market.

Processed product. Utilizing a price elasticity of demand estimate of -1.159 (2) combined with an overall 1.4% reduction in crop output leads to a 1.2% increase in the farm level commodity price for processed apples and an increase in consumer costs for processed apple products of $9.1 million (Table 6). Grower costs would increase an estimated $22.88/A. The change in growers net revenue would decrease by $3.5 million as the increase in apple price would be more than offset by the loss in yield and increase in costs on treated acres. Net returns on acres currently being treated with 2,4-D would decline by $35.41/A. Growers who currently do not treat with 2,4-D would benefit from the higher apple price and their revenues should increase by $35.66/A. No quality downgrading was expected. Thus, the 1992 economic effect for banning 2,4-D on the processed apple market amounts to a net societal loss to producers and consumers of $12.6 million (Table 6).

Fresh product. A price elasticity of demand estimate of -1.348 (2) combined with the uniformly applied 1.4% reduction in crop output leads to a 1% increase in the farm level commodity price for fresh market apples and an overall increase in consumer costs of $50.5 million. Grower costs would increase by $22.88 on acres currently being treated with 2,4-D and overall net revenue would decrease by $20.4 million (Table 6). Net return on treated acres would decrease by $75.72/A, while net return on acres not currently being treated with 2,4-D would increase by $148/A. The net societal effect of a loss of 2,4-D use in fresh market apple production would be a decline in producer and consumer surplus of $70.9 million (Table 6).

The 1992 net societal loss estimate for banning 2,4-D for the processed and fresh apple markets is therefore $83.5 million (Table 6). This loss would be somewhat mitigated on the consumer side by the supply-enhancing effect of imported fresh apples and apple products, though estimates of the potential price-buffering effects from this eventuality happles and apple p

Apricot. About 1,400 acres of apricots are treated with 1,500 pounds of 2,4-D in California and Washington at about 1.1 lb/A. The acreage treated with 2,4-D represents about 6% (Table 1) of the 24,000 acres in apricots in the United States. Apricot acreage in California and Washington made up about 94% of the total national apricot acreage. Growers in Washington state treat 35% of their 1400 apricot acres with 2,4-D while California growers treat 4% of their 21,000 acres.

If 2,4-D were banned, glyphosate would be the alternative herbicide of choice, with about 2,100 pounds expected to replace the 1,500 pounds (Table 5) of 2,4-D currently thought to be applied. A small amount of paraquat would also be used.

Both California and Washington growers would resort to non-chemical weed control methods if 2,4-D were no longer available. In California, disking, in-row cultivation, and mowing would be used on up to 30% of currently treated acres. Washington growers would use the same methods on up to 50% of currently treated acres, while perhaps 35% of apricot acres would be left untreated. Total expenditures for non-chemical weed control in both states would be no more than $3,000.

Yield loss is expected to be about 5% in Washington production if 2,4-D is lost, while little or no loss is expected in California. The estimated weighted average yield loss in the two reporting states is calculated to be 0.20%.

The price elasticity of demand estimate is -0.1509 (7) and represents "processed fruits and vegetables" as we assume most apricot consumption is in the processed form (either dried, canned, or preserved) rather than fresh. The projected reduction of crop output of 0.20% results in an increase in farm level commodity price of 1.3% leading to a loss in consumer surplus of about $1 million (Table 6). Production costs would increase by $27,400 or about $19.13/A (Table 4) on acreage currently treated with 2,4-D. Net revenue would increase by $820,000 or about $16/A on acres currently treated with 2,4-D and almost $42/A on acres that are not currently treated with 2,4-D. The 1992 net societal effect of banning 2,4-D in apricots would be a loss of $180,000 (Table 6) if 2,4-D were banned.

Avocado. A small amount of 2,4-D is used in avocado production in California. About 1% of California's 80,000 avocado acres are treated with 2,4-D, whereas Florida growers use no 2,4-D on their 7,700 acres. A total of about 800 acres are treated with 2,400 pounds (Table 2) at an average rate of 3 lb/A (Table 3) and an expenditure of $7600.

If 2,4-D were no longer available, the herbicide of choice would be glyphosate with the amount used estimated to total about 2000 pounds at an annual cost of $27,000, an increase of $19,000 (Table 6). No non-chemical alternative weed control methods are expected to be used by avocado growers according to the California respondent.

No yield loss is expected and therefore the economic effects are totally described by the change in cost for alternative herbicide materials. The $19,000 increase in costs translates to an increase in per-acre cost of production on acres currently treated with 2,4-D of $24.32. It also indicates a decrease in producer surplus of $19,000, the value of the increase in costs. Because there are no yield effects and subsequent price effects, the 1992 net societal effect for banning 2,4-D in avocados is a loss of $19,000 (Table 6).

Blueberry. Responses from 5 states represented approximately 28% of total cultivated blueberry acres in 1987. These data were extrapolated to account for all 37,000 United States blueberry acres. Of the five responding states, 2,4-D use in blueberry production was reported from Oregon. The use of 2,4-D on 8% of Oregon's 1,900 blueberry acres amounted to an estimated 152 pounds at a cost of $486. Assuming the remaining 27,000 acres of blueberries in the United States were treated similarly, results in an additional 405 acres treated and 405 pounds used at an aggregate cost of $1,780.

The loss of 2,4-D would result in no alternative weed control methods or materials used (Table 5). The estimated weighted-average yield loss (Table 4) for blueberry acres nationally is 0.15%.

The price elasticity of demand estimate (7) represents "other processed fruits and vegetables" as we assume that most blueberries are consumed in that form rather than fresh. The projected reduction in crop output for the represented states of 0.15% results in an increase in farm level commodity price of 1% leading to a loss in consumer surplus of $1.2 million (Table 6). Because no substitute materials would be purchased, production costs would actually decrease by $1,780, the cost formerly expended on 2,4-D, or $3.14/A (Table 4). Because of the increase in cost to the consumer, net revenue to the farmer would increase by $1 million or about $25/A on the currently treated acreage and $33/A on acreage not currently being treated with 2,4-D. The 1992 net societal effect for banning 2,4-D on blueberries is a loss of $200,000 (Table 6).

Cherry. The United States had about 131,000 acres (Table 3) in cherry orchards in 1987, of which approximately 10.5% (Table 1) or 13,800 acres were treated with 2,4-D. Use of 2,4-D was modest among the responding states. The state of Washington had the greatest use, with 15% of its cherry acres being treated with 2,4-D, while California had 11%. A total of 15,000 pounds of 2,4-D are used (Table 2), or about 1.1 lb/A annually (Table 3). Annual expenditures for 2,4-D in cherry production total about $49,000. Negative yield impacts would be registered only in Washington with a predicted yield loss of 5% if 2,4-D were banned. Overall weighted-average yield loss is estimated to be 0.5%.

If 2,4-D were banned, cherry growers would turn to glyphosate and paraquat as alternative chemical controls, with the former being used on 93% of the current 2,4-D treated acres (Table 5). About 6,000 pounds of herbicide substitutes would replace the 15,000 pounds of 2,4-D currently being used. Costs for alternative herbicides would increase by $78,000 above current expenditures for 2,4-D. Additionally, non-chemical control methods would be used extensively. California growers would disk 60% of formerly 2,4-D treated acres. Growers in Washington would disk 20%, cultivate 20%, and mulch 5%. No weed control practices would be used on 35% of Washington cherry orchard acreage currently being treated with 2,4-D. About 30% of Montana cherry orchards would be mowed and cultivated. About $13,000 would be spent on non-chemical weed control methods in all cherry growing states.

A price elasticity of demand of -0.4159 (7), which has been estimated to generically describe the price-demand relationship for "fresh fruits," is used to estimate the consumer and producer impacts of a cancellation of 2,4-D in cherry production. A projected reduction in output of 0.5% (Table 4) combined with the price elasticity estimate mentioned previously results in an estimated increase in farm-level commodity price of 1.2% (Table 6).

The estimated loss in consumer surplus resulting from the loss of 2,4-D in cherry production would be $2.3 million. Production costs would increase by $146,000 or $10.58/A for acres previously treated with 2,4-D. Net revenue would increase by $1.2 million. Net returns for growers on acres currently treated with 2,4-D would decrease by $5.49/A, but it would increase by $23.37/A for growers not using 2,4-D. The net societal loss resulting from a ban on 2,4-D use in cherry production would be $1.1 million.

Coffee. The respondent from Puerto Rico indicated that 2,4-D was used for weed control in coffee. Only 2% of Puerto Rican coffee acreage were treated with 2,4-D (Table 1). Though the use rate is 3 lb/A, only 43 acres (Table 3) were treated using 128 lbs of 2,4-D (Table 2). No other phenoxy herbicide is used in coffee.

The Puerto Rican respondent estimated that 30% of the area currently treated with 2,4-D (Table 5) would be treated with the alternative herbicide, dicamba. The use rate would be lower, but there is greater chance for tree injury with dicamba than with 2,4-D. Production would be decreased by an estimated 8,700 lb or 0.3% of total production (Table 4).

Because there is no known price change or consumer effect, the net effect of banning 2,4-D is a decrease in revenue to farmers of $26,400 (Table 6). Alternative herbicides are available to control some of the broadleaf weeds using preemergence herbicides. If 2,4-D were banned, alternative herbicides would further increase costs of coffee production.

Cranberry. Representatives from four cranberry producing states responded to our questionnaire representing 94% or 26,466 acres (Table 1) of cranberry bog. The data were extrapolated to reach 100% coverage. Average national acreage was calculated for the years 1989 to 1991 (1). About 27,500 acres of cranberries were produced in the represented states. Massachusetts and Wisconsin reported 7% and 15% of acres treated with 2,4-D, respectively. Washington reported 25% of acres treated on 1,400 total acres. No 2,4-D is used on cranberries in New Jersey. Overall, 10% (Table 1) of represented cranberry acres were treated with 7,000 pounds (Table 2) of 2,4-D annually at a rate of 2.6 lb/A (Table 3) for an estimated cost of $22,400.

About 4,500 pounds of alternative herbicides are expected to be used if 2,4-D were banned (Table 2). Glyphosate is expected to be applied to 62% of the acreage currently being treated with 2,4-D (Table 5). Napropamide and dichlobenil would be used in lesser amounts. Costs for alternative herbicides are projected to increase by $57,000 over what is currently being spent by growers for 2,4-D. Reliance on non-chemical methods of weed control would not be extensive. Massachusetts growers are expected to hand weed about 20% of their acres previously treated with 2,4-D, though 35% of such acres are not expected to receive any weed control treatment. Growers in Wisconsin are not expected to use any type of weed control method to substitute for the loss of 2,4-D.

Expected yield loss ranged from 1% in Massachusetts to 10% in Wisconsin. A 4% loss on treated acres is expected in Washington. The weighted-average estimate for yield loss in the crop is 0.65%.

The reduction in yield estimate of 0.65% combined with the price elasticity of demand estimate for "other fresh fruits" of -0.4159 (7) results in an increase in farm-level price of 1.6%. The resulting loss in consumer surplus is expected to reach $2.7 million (Table 6). Production costs would increase by $60,600 or $22/A on acres currently treated with 2,4-D (Table 4). Net revenue is projected to increase by $1.5 million (Table 6). If 2,4-D were banned, net returns on current treated acres would increase by $35/A, while growers who are not currently treating with 2,4-D would experience a $99 per acre increase in net revenue. Because of increased costs to the consumer, the 1992 net societal effect of banning 2,4-D on cranberry is a loss of $1.2 million (Table 6).

Grape. Approximately 27,000 acres of vineyards, or 3.2% of the 833,000 national acreage (Table 3), are treated annually with 2,4-D. The majority of treated acreage occurs in California where 3%, or 21,232 acres receive one 2,4-D application per season for weed control. An estimated 16,700 pounds (Table 2) of 2,4-D are applied to vineyards nationally. If 2,4-D were lost for use in grape production, growers would in many instances go back to non-chemical weed control methods including mowing, disking, and cultivation. Costs of weed control would increase considerably. For instance, in California, where about $34,000 is spent annually on 2,4-D, costs would total about $183,000 on the estimated 68% of the acres formerly treated with 2,4-D. This sum includes the labor, equipment, and fuel costs of disking once per growing season and mowing the vineyard six times.

About 32% of California acreage formerly treated with 2,4-D would receive an alternative herbicide, either glyphosate or paraquat. Approximately 32,000 pounds of glyphosate and 2,400 pounds of paraquat would replace the estimated 10,600 pounds of 2,4-D currently used in California, which would give a 21,500 pound increase in herbicide used if 2,4-D were banned (Table 2). In some instances no substitute weed control methods would be used, as growers may expect the value of yield loss from weeds to be less than the costs of alternative weed control methods. In Oregon, for instance, all acres currently managed with 2,4-D would have no alternative weed control methods applied according to extension weed scientists.

Predicted yield loss varied by region, with Washington and Oregon production expected to decrease by 10% and 7.5%, respectively, on acres formerly treated with 2,4-D. However, no yield loss was expected in California, leading to a weighted-average yield loss estimate of 0.04%.

For the purposes of the economic analysis, grape production was divided into two portions: that used for processed grape products, including wine and juices, and the portion used for fresh consumption. The price elasticities of demand are different for these two market sectors as are market prices. It was assumed that the proportion of grape acreage devoted to production for processing purposes was proportional to the percentage of the crop ending as processed commodities. The same assumption was made for fresh market grapes.

Processed grapes. Acres devoted to grapes for processing were assumed to comprise 86% of total production acres. Using a price elasticity of demand estimate of -0.232 (9), the farm-level price of grapes used for processing purposes would increase by 0.2% leading to an overall short-run increase in consumer costs for processed grape products of $3.8 million (Table 6). Grower revenues would increase by an estimated $2.3 million, because the expected price increase is proportionally greater than the estimated reduction in crop output combined with the increase in costs for weed control on acres currently treated with 2,4-D. Net returns on acreage currently treated with 2,4-D would decrease by $21.35/A, while growers who have not been using 2,4-D could expect an increase in net revenue of $4.61/A. Because no quality downgrading was expected to occur with the use of alternative weed control methods, the overall effect of a 2,4-D ban amounts to a net loss of $1.5 million (Table 6), the summation of the loss in value of consumer surplus and the overall gain in producer surplus.

Fresh grapes. Production acres devoted to fresh market output was assumed to be 14% of total grape acreage, and the price elasticity of demand for fresh market grapes was taken as -1.1795 (7). The farm-lelasticity of demand for fresh market grapes was taken as -1.1795 (7). The farm-level price of grapes used for fresh consumption is expected to increase by 0.03%, leading to (Table 6). Grower revenues would decrease by an estimated $1.1 million, because the expected price increase is proportionally less than the estimated reduction in crop output combined with the increase in costs for weed control on acres currently treated with 2,4-D.

Net returns on acres currently treated with 2,4-D (whether processed or fresh) would decrease by $24.89 per acre (Table 4), while growers who are not currently treating with 2,4-D could expect no change in net revenue. The overall effect of a 2,4-D ban amounts to a net loss of $6.4 million (Table 6), the summation of the loss in value of consumer and producer surplus. The 1992 net societal loss for banning 2,4-D on grapes, when both processed and fresh market sectors are combined, amounts to $7.9 million (Table 6).

Navel orange and grapefruit. Each year, 7,600 pounds of 2,4-D are applied to orange and grapefruit in Arizona and California to stop abscission and delay fruit drop. This allows the fruit to remain on the tree, thereby extending the harvest period by as much as 2 1/2 months. If these fruit could not be "stored" on the trees, there would be an estimated annual loss to growers of $80 million because dropped fruit are lost. The net societal loss would be much greater, but we have not estimated it because of the uncertainty of the costs of imports to replace lost fruit. Without 2,4-D, however, consumers would have less fruit, or more costly fruit, available in the marketplace during late winter and spring.

Nectarine. Responses from three states represented approximately 95% of the nectarine acreage in 1987. Data were extrapolated to 100 percent of nectarine acreage. Use of 2,4-D is fairly extensive in Pennsylvania with 35% of the acreage is treated. California growers treated an estimated 3% and Washington growers an estimated 10% of nectarine acres. The overall weighted-average of acres treated was 4.5% (Table 1). A total of 1,470 pounds of 2,4-D was estimated used on 1,500 acres at about 1 lb/A. Annual expenditures for 2,4-D totaled about $4,700.

Expected alternative herbicides to be used, if 2,4-D were banned, include paraquat, trifluralin, norflurazon, and oxyfluorfen. Paraquat would comprise 70% of alternative herbicide use. A total of about 4,000 pounds of alternative herbicides would replace the 1,470 pounds of 2,4-D in current use (Table 5). Non-chemical methods of weed control would be used extensively in California and Washington. About 55% of California nectarine acreage would be disked and 5% mowed. About 45% of Washington acres would either be disked, cultivated, or mulched. Fully 35% of the Washington acres would have no alternative weed control methods applied.

Yield losses were projected for Washington (5%) and Pennsylvania (15%), though none was projected for California production. Yield reductions would be primarily from reduced pollination of the nectarines due to competition for pollinating insects by flowering broadleaf weeds. Because of the dominance of California production acreage, the overall yield loss estimate was only 0.1%.

A price elasticity of demand estimate for nectarines is taken as similar to "other fresh fruits" and measured as -0.4159 (7). This estimate together with the estimated reduction in crop output gives a 0.2% increase in farm level commodity price. This results in a loss in consumer surplus of $216,000 (Table 6). Production costs would increase by $55,000 or $37.74 per treated acre. Net revenue would increase by $71,000. Net returns on acres currently treated would decrease by $34/A, while growers not currently treating with 2,4-D would experience an increase in net revenue of $6.57/A. The 1992 net societal effect for banning 2,4-D on nectarines is a loss of $145,000 (Table 6).

Peach. Approximately 30,000 acres of peach orchards are treated with 2,4-D representing 13% (Table 1) of the 240,000 acres (Table 3) of peaches grown in the United States in 1987. Use of 2,4-D appears greater in the eastern states represented in the survey. New Jersey reported half of all peach acreage treated with 2,4-D, Pennsylvania 35%, and North Carolina and West Virginia 20%. About 28,500 pounds of 2,4-D are currently applied annually in the reporting states at about 0.95 lb/A

(Table 3). If 2,4-D were lost, the majority of current 2,4-D treated peach acreage would be treated with about 12,600 pounds of glyphosate and 6,300 pounds of paraquat. However, growers would revert to some forms of mechanical weed control on some acreage, though patterns of alternative weed control methods are not uniform. For instance, New Jersey growers would use disking for weed control on 50% of the acreage now treated with 2,4-D and mowing on 10%. Georgia growers would mow 25%. Respondents also predicted that Georgia growers may use no substitute weed control methods on 65% of acres currently treated with 2,4-D. Washington peach growers would use no substitute on 35% of acres currently treated with 2,4-D.

Predicted yield loss of peaches varied regionally. Commodity experts in Pennsylvania and North Carolina expected losses of 15% and 20%, respectively, and commented that long term tree life would be reduced, as well as negative yield and quality impacts experienced, by not having 2,4-D to control broadleaf plants that are the alternate hosts for insects that cause "catfacing" on peaches. Loss is estimated at 5% of the peach crop in Washington if 2,4-D were banned, while no loss is expected in California. The overall weighted-average yield loss estimate is 0.5% of the total crop (Table 4).

Using a price elasticity of demand estimate of -0.4159 (7) and the estimated national yield loss of 0.5% (Table 4), the farm-level commodity price for peaches is expected to increase 1.2% leading to a loss in consumer surplus of about $7.3 million (Table 6). Production costs would increase by $150,000 or $4.94 per treated acre (Table 4). However, net revenue would increase by $4.1 million (Table 6). Net returns on acres currently treated with 2,4-D would increase by $12.70/A, while returns on acres currently not treated with 2,4-D would rise by $30.58. No quality downgrading estimates were provided by the respondents. The 1992 net societal effect of a ban of 2,4-D for use in peach production would be an annual $3.2 million loss (Table 6).

Pear. Approximately 17,000 acres of pear trees are treated with 2,4-D representing about 21% (Table 1) of the 84,000 acres (Table 3) in pears in the United States. The three major producing states are California, Washington, and Oregon. These states represented about 86% of total pear acreage nationwide in 1987, the last year for which comprehensive pear acreage data are available

(Table 1). Use is greatest in Oregon where 40% of the pear acres are treated with 2,4-D; 15% are treated in California and 13% in Washington. About 19,000 pounds of 2,4-D are applied on these acres or about 1.1 lb/A annually (Table 3).

Alternative herbicides of choice if 2,4-D were lost in pear production are glyphosate and paraquat (Table 5). Approximately 28,000 pounds of herbicide alternatives would be used with glyphosate being used on 82% of the acreage currently being treated with 2,4-D. Paraquat would be used on 9% of that acreage, with oryzalin, simazine, diuron, and oxyfluorfen being used on minor portions of the area currently treated with 2,4-D.

Respondents in each state expected growers to use some non-chemical weed control methods if 2,4-D were lost. California growers were expected to mow 30% of pear acreage that currently is treated with 2,4-D. Growers in Oregon would mow 20% and disk 5% of such acres, while Washington growers would use non-chemical methods on 50% of pear acreage currently being treated with 2,4-D and no substitute weed control methods on 35% of such acres. Total estimated yearly expenditures for these practices would be $30,000.

Annual yield loss of pear production in Washington without 2,4-D is estimated to be 5%, in Oregon 3%, while no yield impacts are predicted for pear production in California. The estimated weighted-average yield loss in the three reporting states would therefore be about 0.6%. The total estimated increase in costs for alternative herbicides would be about $345,000 (Table 4).

Using a price elasticity of demand estimate for pears of -0.4159 (7), and a projected reduction in crop output of 0.6% results in an estimated increase in farm level commodity price of 1.4%, leading to a loss in consumer surplus of $3.5 million (Table 6). Production costs would increase by $345,000 or an increase of $22.60 per treated acre (Table 4). Net revenue, however, would increase by approximately $1.66 million (Table 6). The overall effect of a ban of 2,4-D in pear production, including the changes in producer and consumer surplus values, is a 1992 net societal loss of $1.79 million (Table 6).

Pistachio. Approximately 65,000 acres of pistachio trees were grown in the United States in 1991, of which 5% were treated with 2,4-D (Table 1). California represents 100% of pistachio production. Growers use about 3,200 pounds of 2,4-D annually (Table 2) at a rate of 1 lb/A (Table 3).

If 2,4-D were banned for use in pistachio production, growers would not experience a loss of yield (Table 4) because other herbicides would be used in its place. Glyphosate would be used on 64% of the acreage currently treated with 2,4-D, with oxyfluorfen on 26%, and paraquat on 11% (Table 5). There would be an increase of herbicide use from the current 3,200 pounds of 2,4-D to 6,100 pounds of alternative herbicides if 2,4-D were banned (Table 5).

No significant yield loss would occur if 2,4-D were banned, thus the economic effects deal strictly with the increased costs of alternative weed control. Costs would increase by about $34.43/A resulting in a decrease in net revenue to growers using 2,4-D. Consumers would not be affected because output would not diminish and no price effects would be felt. The 1992 net societal effect for banning 2,4-D on pistachios is therefore a loss of $111,000 (Table 6).

Plum and prune. Representatives from California, Oregon, and Washington responded to the questionnaire, accounting for 94% of national plum and prune acreage in 1987. The use of 2,4-D on plum and prune acreage is not extensive. California growers treat about 7.5% or 10,200 acres with 2,4-D in any given year, while Washington growers treat 13% or 290 acres. No 2,4-D use was reported in Oregon. An overall weighted-average of 7.4% of the total acreage receives a 2,4-D application. Approximately 8,000 pounds of 2,4-D (Table 3) is used each year at a cost of $25,800.

About 16,700 pounds of paraquat and oxyfluorfen are expected to be used if 2,4-D were no longer available to plum and prune growers, with paraquat making up about 94% of the total (Table 5). Costs for herbicide control would increase by $231,000. Non-chemical weed control methods would consist mainly of mowing (50%) and hand weeding (10%) in California; and disking (20%), cultivation (20%), and mulching (5%) in Washington. Washington growers are expected to use no substitute weed control methods on 35% of acreage currently being treated with 2,4-D.

The plum and prune crop in California is expected to experience a 10% yield loss without 2,4-D. Yields in Washington may decline by 5%. The national weighted-average loss in yield is estimated to be 0.7% (Table 4).

Combining the reduction in output estimate of 0.7% and the price elasticity of demand value of -0.4159 (7) gives an estimated increase in farm level commodity price of 1.8%. The resulting loss in consumer surplus is expected to be $1.32 million (Table 6). Production costs would increase by $281,000 or $25.27/A. Net revenue would increase by $480,000. Net returns on acres currently treated with 2,4-D would decrease by $20.21/A while growers not currently treating with 2,4-D would benefit by $8.77/A. The 1992 net societal effect for banning 2,4-D on plums and prunes is a loss of $840,000 (Table 6).

Strawberry. Respondents from six of the ten states responding to the questionnaire indicated extensive use of 2,4-D in strawberries. Extension specialists in Pennsylvania reported 2,4-D use on 90% of planted acres, New York and Ohio on 80% each, and Wisconsin and Maine on 75% each. However, these states each have less than 3,000 acres in strawberry production. In California, the largest strawberry producing state with 21,000 acres, use of 2,4-D is reported as insignificant because of methyl bromide fumigation. The respondent in Florida also reported little use of 2,4-D on 5,400 acres of strawberries. Average total acreage in strawberries for the United States during the 1989 to 1991 period was about 46,000 acres. About 16% (Table 1) or 7,200 acres of strawberries were treated with 9,900 pounds of 2,4-D (Table 2) at a rate of 1.4 lb/A (Table 3) and a total cost of $32,000.

Growers are projected to use few herbicide alternatives if 2,4-D were banned. A total of 2,200 pounds of substitute herbicides, comprised mostly of napropamide (51%) and DCPA (41%) (Table 5), would replace the 9,900 pounds of 2,4-D currently in use. Weed control costs would increase approximately $76,000 above current grower expenditures for 2,4-D. The cost of chemical alternatives would actually decrease, being replaced by expenditures for non-chemical control methods. About $80,000 is projected to be spent exclusively on hand weeding. Connecticut, New York, and Wisconsin growers are expected to hand weed all of their strawberry acres, Ohio 80%, Maine 67%, and Oregon 40%. Pennsylvania growers are predicted to use no alternative weed control methods if 2,4-D is no longer available.

In states with extensive current 2,4-D use, yield loss estimates following a ban would be significant. Estimates of up to 60% yield loss were received from state commodity experts. However, overall weighted-average yield loss was predicted to be only 1% nationwide (Table 4) because of the predominance of California acreage on which no 2,4-D is used. Combining the estimated reduction in crop output of 1% and a price elasticity of demand estimate of -0.4159 results in a projected increase in farm level commodity price of 2.5% (Table 6). The resulting loss in consumer surplus is expected to reach $22 million (Table 6). Production costs would increase by $71,400 (Table 4) or about $10/A on currently treated acreage. Net revenue to strawberry producers is expected to increase by $12.6 million (Table 6). If 2,4-D were banned, net returns on those acres currently being treated with 2,4-D are projected to increase by $266/A while growers who are not currently using 2,4-D would see net returns rise by $481/A. The 1992 net societal loss for banning 2,4-D on strawberries is projected as $9.4 million (Table 6).

Walnut. Approximately 213,000 acres of walnut for agricultural production existed in the United States in 1987, 210,000 in California and 3,000 in Oregon, the two states for which questionnaire responses were received. Responding states represent about 99% of total walnut acreage. An estimated 19,000 acres, or 9%, were treated with 2,4-D, all in California (Table 1). California walnut growers use about 15,600 pounds of 2,4-D each year (Table 2).

If 2,4-D were banned for use in walnut production, many growers would use other herbicides, plus some non-chemical methods. About 48,400 pounds (Table 2) of alternative herbicides would replace the 2,4-D currently in use, comprised principally of glyphosate (82%), simazine (8%), diuron (6%), and oxyfluorfen (4%) (Table 5). In addition, it is thought that about 10% of the California acreage currently treated with 2,4-D would be disked for weed control at a total cost of about $11,300. The cost of weed control using these alternative methods would total approximately $623,800, (Table 4) a significant increase over the $50,000 currently being spent for 2,4-D. Costs of weed control would increase by about $624,000 including both alternative herbicides and non-chemical methods.

No significant yield loss is predicted, indicating effective weed control is expected to be achieved using alternative herbicides and non-chemical methods. The economic effects therefore deal strictly with the increased costs of alternative weed control. Costs per treated acre would increase by about $33 resulting in a decrease in net revenue of $624,000 (Table 4) for growers currently using 2,4-D. Consumers would not be affected because output would not diminish and no price effects would be felt. Average walnut output would remain at about 1.1 tons/A. The 1992 net societal effect for banning 2,4-D in walnuts is therefore a loss of $624,000 (Table 6).

WEED CONTROL ALTERNATIVES IF 2,4-D WERE LOST

Alternative herbicides. Two postemergence herbicides, paraquat and glyphosate, would have greatly increased use with the loss of 2,4-D. Both of these materials are registered on all orchard and vineyard crops on which 2,4-D is currently registered. There are some major differences between these products and 2,4-D. Glyphosate controls the weeds that 2,4-D controls; however, glyphosate is nonselective and does not give the grower the option to selectively control broadleaf weeds and leave grass for ground cover in orchards and vineyards. Paraquat is a contact herbicide that is most effective on annual grasses. It will only suppress perennials, thus multiple applications are required to give broadleaf weed control similar to 2,4-D. Dicamba may substitute for 2,4-D in coffee, but there is greater concern with tree injury with dicamba than with 2,4-D.

Preemergence herbicides that will control the same annual weeds that 2,4-D controls are available in some crops. Alternative preemergence herbicides are listed by crop (Table 7). Spectrum of weed control for the different preemergence herbicides does not allow any one of them to totally replace 2,4-D. With few exceptions, perennial weeds are not controlled with the preemergence herbicides. One exception is the use of trifluralin layered beneath the topsoil with a subsurface blade to suppress field bindweed. This practice can be used in almond, apricot, grape, nectarine, peach, pecan, plum, prune, and walnut. The postemergence activity of 2,4-D is used to supplement preemergence herbicides or other cultural practices rather than as a substitute for them.

Several postemergence herbicides are available (Table 8), but none have the characteristics needed to totally replace 2,4-D.

Other alternative methods. There is always an alternate method of weed control. Cultivation with disks, hoes, harrows, and in-row cultivators (of many types) all have a place for annual weed control in orchards and vineyards. Soil conditions, such as texture and amount of rocks, orchard or vineyard topography, and weed species will determine which one of these implements will be most effective. Hand hoeing is effective on annual weeds, but it is labor intensive and costly. The mechanical methods and hand weeding are not effective for perennial weed control in the orchard, and mechanical methods often make the weed problem more severe because of spreading weed propagules in the orchard and vineyard.

Farmers have shown a renewed interest in flaming for the control of weeds. Flaming is a practice that has been available for many years; however, fuel prices have been high, and flaming has the disadvantages of creating smoke and consuming fossil fuel. Propane is used as the energy source. Flaming is used as a selective treatment around the base of mature trees or as a nonselective treatment between tree or vine rows. Flaming is effective only on young weeds, with better control of annual broadleaf weeds than grasses. Care is required so that the crop is not damaged by fire in dry vegetation, particularly around the base of trees. Trees and vines may be damaged from any of these non-chemical treatments.

Mulching with straw, biomass grown in the orchard or vineyard, or synthetic organic fabrics is being tried with varying success. Often mulching fails to control all weeds because not enough mulch is available, distribution is uneven, or perennial weeds such as field bindweed grow through the mulch.

PLANT GROWTH REGULATOR ALTERNATIVES IF 2,4-D IS LOST

Products that have been evaluated for alternative use in citrus production have not been as effective or as safe to the crop as 2,4-D. Indoleacetic acid (IAA), indolebutyric acid (IBA), naphthalene acetic acid (NAA), brassinolide, triclopyr, picolinic acid, and gibberellic acid have all been evaluated alone or in combination. In general, they either were not as efficacious as 2,4-D or were phytotoxic to the crop.

IMPACT OF THE LOSS OF ALL PHENOXY HERBICIDES

No phenoxy herbicides other than 2,4-D are registered in orchard, vineyard, and soft fruit crops.

COMPELLING REASONS FOR RETAINING 2,4-D

WEED RESISTANCE MANAGEMENT

There was concern by the respondents that the increased use of glyphosate as a replacement for 2,4-D in orchards and vineyards would lead to the development of glyphosate resistance in weeds now susceptible to that herbicide. As a selective herbicide, 2,4-D allows grass cover crops to grow between the vines and trees, thus increasing the competitive pressure on invading weed species. This competition has assisted growers in reducing weeds and lessening the need for herbicides. The unique mode-of-action of 2,4-D makes it valuable in a weed-resistance management program. Because 2,4-D has multiple-sites-of-action, there is less chance of weeds developing resistance to it than to the single-site-of-action herbicides that have been developed relatively recently. Thus, 2,4-D makes a valuable supplemental or rotational herbicide for managing weeds.

FUTURE WEED MANAGEMENT OPTIONS

In the near future there may be two new postemergence herbicides registered and used in orchards and vineyards. One of these materials, glufosinate, is a nonselective contact herbicide, and the other is a nonselective translocated herbicide, sulfosate. In some states, another herbicide, clopyralid, has shown selectivity in some tree crops and may eventually be registered for broadleaf control, but it probably will not receive registration in all states. Currently no preemergence herbicides are known that could give similar broadleaf activity as 2,4-D. In the distant future, there is technology being developed that gives synergism with phenoxy herbicides, which should allow a reduction of use rates of phenoxy herbicides. Application equipment is available that detects vegetation and bare soil, which permits spraying only the weeds and thus reducing the amount of herbicide that must be applied in an orchard or vineyard. Depending upon the amount of weed cover, postemergence herbicides can be markedly reduced with this weed sensing equipment.

Cultivation equipment will continue to improve at controlling weeds around trees or vines without damaging them. The equipment should also reduce the island of weeds around the base of the tree or vine. As cultivation increases, however, additional fossil fuel and labor will be required to operate the machinery.

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Table 1. Orchard, vineyard, and soft fruit acreage reported in survey; number of states reporting; portion of total acreage covered in survey; and portion of total acreage treated in 1992 with 2,4-D in the United States and Puerto Rico.

Crop	Acres included in survey (000)	States represented in survey No.	Portion of the total acreage in production: In survey %	Portion of the total acreage in production: Treated with 2,4-D %
Almond	401.0	1	99	15.5
Apple	379.0	22	63	25.6
Appricot	22.4	2	94	5.9
Avocado	87.7	2	100	0.9
Blueberry	10.3	5	28	1.5
Cherry	39.5	6	30	10.5
Coffee	2.1	1	100	2.0
Cranberry	26.5	4	94	10.0
Grape	762.9	6	99	3.2
Nectarine	31.7	3	95	4.5
Peach	151.9	11	63	12.7
Pear	72.8	3	86	20.9
Pistachio	65.0	1	100	5.0
Plum and prune	142.2	3	94	7.4
Strawberry	41.5	10	90	15.6
Walnut	213.0	2	99	8.9

Table 2. Use of 2,4-D on orchards, vineyards, and soft fruit in the United States and Puerto Rico during 1992 and estimated use of alternative herbicides in the event of a ban on 2,4-D.

Current 2,4-D Estimated alternative Change in herbicide use

Crop use herbicide use from 2,4-D

lb (000)

Almond 62.10 93.20 31.10

Apple 188.00 140.00 -48.00

Apricot 1.50 2.10 0.60

Avocado 2.40 2.00 -0.40

Blueberry 0.56 0.00 -0.56

Cherry 15.00 6.00 -9.00

Coffee 0.13 0.06 -0.06

Cranberry 7.00 4.50 -2.50

Grape 16.70 38.20 21.50

Nectarine 1.50 4.00 2.50

Peach 28.50 19.10 -9.40

Pear 19.00 27.80 8.80

Pistachio 3.20 6.10 2.90

Plum and prune 8.00 16.70 8.70

Strawberry 9.90 2.20 -7.70

Walnut 15.60 48.40 32.80

Total 377.09 410.36 31.37

Table 3

Table 3. Annual production, price, and 2,4-D use in orchards, vineyards, and soft fruit in States and Puerto Rico.

Crop	Acres in production[a]	Production[b] and yield units	Price per unit	2,4-D use[c] Acres treated		Pounds
	----------(000)-----------		$	(000)	%	(000)
Almond	401.0	547,000 lb	1.00	62.10	15.5	62.10
Apple	601.0	---	---	154.00	25.6	188.00
fresh	----	3,088,371 lb	0.18	----	----	----
processed	----[d]	4,067,435 lb	0.87	----	----	----
Apricot	24.0	112 ton	651.83	1.40	5.9	1.50
Avocado	87.0	130 ton	1,597.00	0.80	0.9	2.40
Blueberry	37.0	26,267 lb	1.23	0.60	1.5	0.56
Cherry	131.0	96 ton	784.83	13.80	10.5	15.00
Coffee	2.1	2,850 lb	2.99	0.04	2.0	0.13
Cranberry	27.5	3,587 bbl	45.67	2.70	10.0	7.00
Grape	833.0	----	----	27.00	3.2	16.70
processed	----	11,293,700 lb	1.36	----	----	----
fresh	----	4,834 ton	450.61	----	----	----
Nectarine	33.0	226 ton	430.87	1.50	4.5	1.47
Peach	240.0	986,600 lb	0.25	30.00	12.7	28.50
Pear	84.0	896 ton	283.44	17.00	21.0	19.00
Pistachio	65.0	78,667 lb	1.30	3.20	5.0	3.20
Plum and prune	151.0	242 ton	293.00	10.50	7.4	8.00
Strawberry	46.0	12,244 cwt	69.67	7.20	15.6	9.90
Walnut	213.0	238 ton	1,063.00	19.00	9.0	15.60
Total	2,975.6	----	----	350.84	11.8	379.06

[a]Data for 1987.
[b]Average for 1989 to 1991.
[c]Based on a 1993 survey of 1992 data.
[d]Not available.

Table 4. Estimated changes in production and in cost of production of orchards, vineyards, and soft fruit in the United States and Puerto Rico during 1992 with the loss of 2,4-D.[a]

Crop	Production change: Quantity and yield units (000)	Production change: Proportion of total %	Cost change per acre previously treated with 2,4-D $	Total cost change $(000)
Almond	0.00 lb	0.00	17.16	1,065.0
Apple	-43,237.00 lb	-1.40	22.88	3,524.0
Apricot	-0.22 ton	-0.20	19.13	27.4
Avocado	0.00 ton	0.00	24.32	19.3
Blueberry	-40.00 lb	-0.15	-3.14	-0.2
Cherry	0.50 ton	-0.51	10.58	146.0
Coffee	-8.70 lb	-0.30	15.80	<1.0
Cranberry	-24.00 bbl	-0.65	22.00	60.6
Grape	-4,266.00 lb	-0.04	24.89	764.2
Nectarine	-0.21 ton	-0.09	37.74	55.0
Peach	-4,900.00 lb	-0.50	4.94	150.1
Pear	-5.00 ton	-0.57	22.60	345.0
Pistachio	0.00 lb	0.00	34.43	111.2
Plum and prune	-1.80 ton	-0.73	25.27	281.2
Strawberry	-129.00 cwt	-1.10	10.00	71.4
Walnut	0.00 ton	0.00	32.97	623.8

[a]The only phenoxy herbicide used in these crops is 2,4-D.

Elmor-table-ta

Table 5. Percent of orchard, vineyard, and soft fruit acreage treated with 2,4-D that is projected to be treated with herbicide alternatives under a 2,4-D ban; and projected quantities of alternatives as compared to 2,4-D use in the United States and Puerto Rico during 1992.

Crop	DCPA	Dicamba	Dichlobenil	Diruon	Glyphosate	Metham	Napropamide
lb (000)							
Almond	0	0	0	75	0	0	0
Apple	0	0	2	0	78	0	0
Apricot	0	0	0	0	99	0	0
Avocado	0	0	0	0	100	0	0
Blueberry	0	0	0	0	0	0	0
Cherry	0	0	0	0	93	0	0
Coffee	0	30	0	0	0	0	0
Cranberry	0	0	16	0	62	0	22
Grape	0	0	0	0	93	0	0
Nectarine	0	0	0	0	0	0	0
Peach	0	0	0	0	64	4	0
Pear	0	0	0	2	82	0	0
Pistachio	0	0	0	0	64	0	0
Plum and prune	0	0	0	0	0	0	0
Strawberry	41	0	0	0	0	0	51
Walnut	0	0	0	6	82	0	0
Total							

Elmor-table-tb

Table 6. Estimated economic effect of a 2,4-D[a] ban in orchard, vineyard, and soft fruit production in the United States and Puerto Rico during 1992.

Crop	Price change	Net revenue change	Consumer effect	Net societal effect
	%	--------------$ (000)--------------		
Almond	0.00	-1,065	0	-1,065
Apple (processed)	1.20	-3,500	-9,100	-12,600
Apple (fresh)	1.00	-20,400	-50,500	-70,900
Apricot	1.30	820	-1,000	-180
Avocado	0.00	-19	0	-19
Blueberry	1.00	1,000	-1,200	-200
Cherry	1.20	1,182	-2,280	-1,098
Coffee	0.00	-26	0	-26
Cranberry	1.60	1,500	-2,700	-1,200
Grape (processed)	0.16	2,300	-3,800	-1,500
Grape (fresh)	0.03	-1,000	-5,300	-6,400
Nectarine	0.20	71	-216	-145
Peach	1.20	4,100	-7,300	-3,200
Pear	1.40	1,656	-3,449	-1,793
Pistachio	0.00	-111	0	-111
Plum and prune	1.80	480	1,320	-840
Strawberry	2.50	12,600	-22,000	-9,400
Walnut	0.00	-624	0	-624
Total of all crops		-1,136	-110,165	-111,307

[a]The only phenoxy herbicide used in these crops is 2,4-D.

Elmor-tc-table 7

Table 7. Alternative preemergence herbicides[a] available for orchards, vineyards, and soft
2,4-D were banned in the United States and Puerto Rico during 1992.

		Crop	DCPA	Dichlobenil		Diuron	EPTC	Hexazinone		Napropamide
Almond	N[b]	N	N	R[c]	N	R	R	R	R	NB[d]
Apple	N	R	R	N	N	R	R	R	R	NB
Apricot	N	N	N	N	N	R	R	R	R	NB
Avocado	N	N	R	N	N	R	N	R	R	N
Blueberry		N	R	R	N	R	R	R	R	N
Cherry	N	R	N	N	N	R	R	R	R	NB
Coffee	N	N	N	N	N	N	N	N	R	N
Cranberry		N	R	N	N	N	R	N	N	N
Grape	N	R	R	N	N	R	R	R	R	NB
Nectarine		N	R	N	N	N	R	R	R	R
Peach	N	R	R	N	N	R	R	R	R	NB
Pear	N	R	R	N	N	R	R	R	R	NB
Pistachio		N	N	N	N	N	R	N	R	N
Plum and prune		N	R	N	N	N	R	N	R	R
Strawberry		R	N	N	N	N	R	N	N	N
Walnut	N	N	R	R	N	R	R	R	R	NB

[a] May not be registered in all states, restrictions on use differ by state, and speci
[b] N = not registered.
[c] R = registered.
[d] NB = use on non-bearing trees only.

Table 8 Alternative postemergence herbicidesa available for orchards, vineyards, and soft fruit if 2,4-D were banned in the United States and Puerto Rico during 1992.

Crop	Glyphosate	MSMA	Paraquat	Sulfosate
Almond	Rb	NBc	R	NB
Apple	R	NB	R	NB
Apricot	R	Nd	R	NB
Avocado	R	N	R	NB
Blueberry	R	N	R	NB
Cherry	R	NB	R	NB
Coffee	R	N	R	NB
Cranberry	R	N	N	NB
Grape	R	N	R	NB
Nectarine	R	N	R	NB
Peach	R	NB	R	NB
Pear	R	NB	R	NB
Pistachio	R	N	R	NB
Plum and prune	R	NB	R	NB
Strawberry	N	N	R	N
Walnut	R	NB	R	NB

aMay not be registered in all states, restrictions on use differ by state, and special local needs registrations may apply.

bR = registered.

cNB = registered for non-bearing trees only.

dN = not registered.

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Chapter 11

Phenoxy Herbicides in Rights-of-Way and Forestry in the United States

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Abstract. Phenoxy herbicides are used in all major areas of road, railroad, and electrical rights-of-way management and in intensive forest production in the United States. Small amounts are used for pipeline maintenance. Approximately a million pounds of 2,4-D are used annually in roadside vegetation maintenance. About 100,000 pounds are used annually on railroad rights-of-way, about the same on electrical utility rights-of-way, and about 60,000 pounds are used for pipeline maintenance. Some 22,000 pounds of diclorprop are used for electrical rights-of-way, and diclorprop and MCPA are used along highways. Triclopyr, picloram, and dicamba use would increase in the absence of phenoxy herbicides. If the phenoxy herbicides were banned, the estimated increase in annual cost for vegetation management on rights-of-way from substituting alternative herbicides for 2,4-D would be $19,063,800, and $300,000 for substituting for diclorprop. Thus, the annual net societal loss from a ban of all phenoxy herbicides in rights-of-way is estimated to be $19.36 million for 1992.

Forest applications for enhancement of timber production entail application of some 208,000 pounds of 2,4-D and 12,000 pounds of diclorprop per year. Uses of phenoxy herbicides in forests are modest except in the high-production areas of Oregon, Washington, California, and Idaho. Applications in the Northwest are mostly by helicopter, but ground application systems prevail elsewhere. Phenoxy herbicides are used primarily for preparing sites for planting, usually in combination with other herbicides or fire and for releasing conifers from red alder or evergreen shrub species. Diclorprop is the only phenoxy herbicide other than 2,4-D used for forestry, and its use is very limited. Diclorprop is not registered in California, where its use would be greatest. Alternatives, among herbicides, include substitution with triclopyr, glyphosate, imazapyr, and picloram. Intensive mechanical site preparation and fire would also be used more widely.

Phenoxy herbicides currently contribute an estimated $898 million to the present net value of forests in the United States. Annual increases in operating costs in forestry from substituting for 2,4-D would be $17,209,400, and for diclorprop, $605,000. Thus, the annual net societal loss from a ban of all phenoxy herbicides in forestry is estimated to be $17.8 million for 1992.

I. RIGHTS-OF-WAY

INTRODUCTION

There are over 3 million miles of paved and unpaved roadways, 170,000 miles of operating railroads, 6.1 million miles of electrical lines (87% distribution and 13% transmission), and 1.3 million miles of pipelines in the continental United States. Maintenance of vegetation along these rights-of-way requires treatment of vegetation with herbicides on some 3.9 million acres per year. Because of the enormous investment in facilities, the protective role of these weed management practices is of major economic importance.

There are minor differences among types of rights-of-way treatments, although they all have features in common, including registration status. Thus, they will be treated separately, where needed, after consideration of their similar features.

Data sources for rights-of-way information were from the NAPIAP questionnaire for noncroplands, and also from industry-supplied Doane Marketing Research and Kline Market research data from 1993. The questionnaire data were fragmentary, but the industrial data were more comprehensive. The industrial market survey data appeared reasonable in terms of the author's conversations with contractors, vegetation managers, and consultants.

Rights-of-way uses of phenoxy herbicides are generally for selective postemergence control of perennial broadleaf forbs and woody plants where they interfere with visibility, clog ditches, interfere with conductors, or pose an environmental problem. Phenoxy herbicides are typically applied in tank mixes with one or more other products to permit fewer applications to handle complex weed problems.

Most products are applied by ground equipment. Some pipelines and railroads are treated by aircraft in remote areas and where rights-of-way are clear of obstacles. Aircraft are seldom used on transmission lines. By far, most herbicide treatments are applied by truck-mounted sprayers, and by spray trains where long runs are possible. Treatments are applied by back-pack sprayers for ornamental plantings, and around spot facilities such as pump stations on pipelines, valves, switches, and near water.

Intervals between applications generally range from 3 to 8 years, depending on climate and proportion of woody species. Applications may be more frequent in the South, and in states where noxious weeds prevail.

REGISTRATION SUMMARY

Phenoxy herbicides registered for use on rights-of-way include 2,4-D acid, amine, and ester; and diclorprop ester formulations. MCPA is not currently registered in forestry in the United States, but is registered for noncropland uses to include rights-of-way, and it showed up on questionnaires describing usage. Both aerial and ground applications and a variety of tank mixes are permitted, or at least not prohibited. Applications include broadcast application of one tank mix containing up to 4 lb/A of 2,4-D ester; 2,4-D amine is also registered for general rights-of-way use. Diclorprop ester may be applied at up to 11.1 lb/A, but the amine is not registered. MCPA is used as the amine salt only. Some 1.26 million pounds of 2,4-D and 22,000 pounds of diclorprop are used on rights-of-way under these registrations.

Tank mixes specified on labels for general rights-of-way applications include combinations with triclopyr, picloram, dicamba, and MSMA. Soil residual products are also mixed with 2,4-D, including diuron, metsulfuron, atrazine, clopyralid, bentazon, and tribenuron.

Phenoxy herbicides are generally applied in the spring in most regions, but are also applied in the fall in the South. Normal rates of application range from 1 to 2 lb/A for each application despite registration of higher rates for use on rights-of-way.

CURRENT CONTROL METHODS

Phenoxy herbicides constitute a small percentage of dollar investments in rights-of-way vegetation management, but they rank high in amounts used and acres treated. On highways, 18% of total herbicide poundage is 2,4-D, third only to glyphosate (38%) and MSMA (20%). The phenoxy herbicides are often mixed with dicamba or triclopyr to enhance efficacy.

Phenoxy herbicides are involved in 39% of all herbicide applications along railroads. These include control in ballast, in mixtures with diuron and sulfometuron in yards, or with glyphosate and sulfometuron on railroad mainlines and branches. Other mixtures include diuron plus tebuthiuron, diuron plus imazapyr, and others.

Electric utility personnel apply more triclopyr (23%) and glyphosate (25%) than any other herbicide. Picloram products, including those formulated with 2,4-D, account for 8% of total treated acres, and those treated with 2,4-D without picloram account for an additional 5%. Imazapyr usage is similar to that of picloram. Cutting, mowing, and other non-chemical methods are widely used by electric utility personnel near population centers.

Pipeline use involves a substantial amount of triclopyr and fosamine, each representing 23% of total herbicide used, but with triclopyr being used on more area. Diuron use amounts to 11% of the product used, but 2,4-D, at 10% of the herbicide poundage, covers a disproportionately larger area because of the low rate used. Pipeline maintenance often relies on mowing near urban areas. It is significant that 95% of all pipelines are in cities, and are covered by paving or structures of some type, hence the relatively low usage of herbicides.

Total annual use of phenoxy herbicides for rights-of-way is about 1,282,000 pounds, of which 22,000 pounds is diclorprop and the rest 2,4-D, according to industrial rights-of-way sources. Data from the NAPIAP questionnaire were fragmentary, in that 20 of 50 states responded, of which 12 reported significant phenoxy herbicide usage. Expanding this response sample to the entire United States, the estimate was 2.2 million pounds of phenoxy herbicides used annually on 1.3 million acres. Some bias was likely in that the densely populated states have a higher-than-average fraction of total rights-of-way in urban areas where vegetation control is not necessary, or where mechanical (mowing) would be the method of choice. Thus, the lower estimate of 1,282,000 pounds of phenoxy herbicides used annually is considered the more reliable. Hence, this figure was used in the calculation of cost savings from use of phenoxy herbicides as compared with alternative herbicides.

DETERMINATION OF BENEFITS AND COSTS

Determination of benefits for rights-of-way control may be in terms of relative costs of alternative vegetation control programs, or frequency of retreatment. Because selection of alternative methods inevitably changes intervals between treatments and also other "values", some of which may be intangible, the cost benefit analysis of herbicide use is fraught with difficulty. For this purpose, one assumes that the intangible value of a product for which there are reasonable substitutes is specific to the program of treatment, rather than to the specific products used. Hence intangibles are omitted from this analysis.

Industrial management sources provided the costs per acre per application of phenoxy herbicides and the two most common alternatives for rights-of-way control shown in Table 1 (expressed as ranges of cost in $/A):

Table 1. Estimated vegetation management costs along rights-of-way in the United States during 1992.

Weed management costs along rights-of-way	With phenoxy herbicide	Alternatives without phenoxy herbicides[a]	
		1	2
	$/A		
Roadsides	2.31 - 12.30	13.54 - 108.00	18.00 - 54.00
Electrical lines	6.15 - 9.22	15.00-180.00	65.00 - 130.00
Railroads	1.44 - 5.75	10.62 -85.00	7.38 - 59.00
Pipelines	3.08 - 13.30	4.70 -78.30	13.20 -132.00

a Alternatives vary by utility according to ratio of triclopyr, picloram, and dicamba, with rates of triclopyr and dicamba dominant in the two alternatives.

In all cases, alternatives capable of controlling broadleaf weeds are triclopyr, dicamba, and picloram. However, costs cited were often the contributions of these products when used in tank mixes, hence the bare costs cannot be extrawere often the contributions of these products when used in tank mixes, hence the bare costs cannot be extracted with precision. As a substitute procedure, one may calculate the amount of an alternative mix component in the absence of the phenoxy herbicide, and multiply that amount by the price per pound to approximate the cost of switching to alternative 1, which was triclopyr in three out of four utilities. The typical use rates of 2,4-D and triclopyr were in the same range for all four utilities. The price of 2,4-D ester averaged $2.87/lb, and that of triclopyr ester was $18.00/lb. Thus, an estimate for the annual cost saving for using 2,4-D as compared with the next alternative would be the cost differential times the total pounds of 2,4-D used by the utilities (1,260,000 pound) = $19,063,800 for 2,4-D and roughly $300,000 for diclorprop. Thus, the net societal loss from a ban of all phenoxy herbicides in rights-of-way is estimated to be $19.36 million annually. This amount would be decreased somewhat if it were det

II. FORESTRY

INTRODUCTION

Commercially productive forest lands cover approximately 25% of continental United States. Timber yields of over 50 billion board feet per year at prices exceeding $250 per thousand board feet (Mbf) provide annual revenues to growers of over $13 billion. As demands for forest products increased since World War II, it became apparent that artificial regeneration and intensive management would be necessary to supplement production from existing natural stands of timber. As plantation management increased in scope during the 1940's, it also became apparent that vegetation management in plantations would be necessary to increase their productivity and to avoid losses due to regeneration of brush and hardwoods of low value (3,10). Competition from fast-growing shrubs and hardwoods appeared among the most important and widespread threats to artificial regeneration of valuable timber species (3,7,10).

Traditional mechanical methods of weeding forests are dangerous to workers, costly, and labor-intensive. They require cutting tools, heavy mechanical equipment, and potentially toxic fuels. The cost and administrative difficulty in accomplishing vegetation management programs, on the scale needed, led to an active search for substitutes that would be effective over large areas. Herbicides became the vegetation management tool most widely applicable for silvicultural use because of their efficacy, safety, and low cost. Phenoxy herbicides, primarily 2,4-D and 2,4,5-T, were found to control brush selectively in conifers, and they were the only herbicides in forestry use on a major scale before 1970. Phenoxy herbicides were found to be effective in the late 1940's, and their use peaked in the 1960's and 1970's. By 1958, two major compilations of brush control studies had been published, one for the Pacific Northwest, and one for the eastern Canadian provinces and Northeastern States (3,10). In the late 1940's, the USDA Forest Service initiated brush control studies with 2,4-D and other phenoxy herbicides (5,6). Early results were promising enough to lead to extensive testing of several phenoxy herbicides and other herbicides available at that time. By the 1960's, 2,4-D had become an important tool in reforestation and releasing of commercially important conifer species (Figure 1). Although on a much smaller scale, diclorprop is also used. This product has recently been shown to be selective for conifer release in pine plantations (4). Newton and Knight (7) describe some of the herbicide recommendations involving 2,4-D in the three major forest regions of the United States.

Although its use has somewhat diminished, 2,4-D remains an important tool for trunk injection nationwide and selective control of brush in Northwestern conifer forests. It is also a component of numerous mixtures for site preparation, but it is seldom used alone anymore for this purpose.

REGISTRATION SUMMARY

Registered uses for 2,4-D in forest management include selective weeding (conifer release), forest site preparation (nonselective use before planting), forest roadside applications, stump treatment, and trunk injection for removal of hardwoods. Esters of 2,4-D are registered for all of these uses except trunk injection; amines are used for trunk injection, stump treatment, and spot spraying in the South, and also for mixing with other products, such as picloram, in formulations that are registered for site preparation. Diclorprop is also registered for use in site preparation and conifer release. Although diclorprop has a federal label, this registration is not authorized in California, thereby excluding the area of considerable benefit to forests.

Most 2,4-D is applied to forests by aircraft, principally helicopters. Application rates are generally 1 to 2 lb/A, but labels permit up to 4 lb/A in site preparation.

Phenoxy herbicides are registered and generally used in forestry as a component of tank mixes. Their contribution to the total prescription varies with each situation, hence is not estimable in terms of actual benefits achieved. At present, 2,4-D may be used in tank mixes with any herbicide that is registered for use alone, unless specifically prohibited. This applies to most site preparation operations, and to release applications in most of the northern coniferous forest types. Present use is concentrated in the Pacific Northwest. Under these registrations, a crude estimate places use level of both phenoxy herbicides at some 220,000 pounds applied to about 116,000 acres per year. Most of this is applied by aircraft at 2 lb/A for conifer release.

WEED LOSSES AND DETERMINATION OF BENEFITS

Determination of net benefits in forests is complicated by the immense rate of change in values of timber in recent years. This has culminated in radical price increases since decreased National Forest harvest levels began in 1992 in response to litigation over the northern spotted owl in the Pacific Northwest. Between 1990 and 1993, the price paid to the landowner per Mbf of timber (stumpage value) for coniferous timber has roughly quadrupled in the Pacific Northwest, and this has been reflected in commensurate increases around the country. Present valuations are based on relative costs of alternatives, and if there are increases in present net value (PNV) of the resource. PNV reflects the net value of the resource as a perpetual series of potential future income after adjusting for all costs of operation. This is based on the value of all future harvests, discounted to the present according to a realistic rahas culminated in radical price increases since decreased National Forest harvest levels began in 1992 in response

Valuation of the contributions of a specific herbicide is based on the contributions of a production practice of which it is a part. In economic terms, benefit is measured by the increase in value of the harvested crop after discounting its future value to the present by compound interest, i.e., its increased present value. The value of a forest enterprise capable of growing an infinite series of crops whose value increments are increased more than the cost of obtaining the increase is presently equal to the sum of its discounted crops. When the herbicide is just a part of a production program, as in tank mixes or as a part of operations not otherwise involving herbicides, the weed management value is blurred by many interactions. Thus, valuation of the impact of a herbicide is far from precise.

A good example of uncounted benefits is where 2,4-D is used to control broadleaf weeds to achieve control of pocket gophers, which also consume tree roots. The herbicide promotes seedling growth both by conserving water and reducing root destruction from mechanical removal of weeds, but the seedlings only show improved performance, with no reflection of which problem has been solved. The following discussion summarizes some of the practices of which phenoxy herbicides are a part, and runs through some calculations of value contributions.

Value impacts from weeds in timber. Hardwood and shrub competition losses cannot be estimated with precision. Burkhart and Sprintz (1) have developed a generalized model for southern pine reflecting impact on pine yield when various components of competing hardwoods are associated with plantation development. Their model illustrates that when hardwood composition increases from none to 20%, harvest value of all products on an average site decrease from $6,491 to $2,430 or a loss of roughly two thirds of the potential value, and that this value loss can be recovered by herbicide treatment. However, this model was developed in a region where very little phenoxy herbicide is used, so it has limited utility for our purposes, apart from generalized estimates for small woodland owners in the South.

Most phenoxy herbicide use in forestry occurs in the Pacific Northwest. The types of loss there from not using phenoxy herbicides range from complete plantation failure, resulting from hardwood domination, to lengthening of production cycles. Heterogeneity of stands and reduced product quality also occur under the influence of woody weeds, leading to variable product quality and value decreases. There are also losses from damage from wildlife, such as pocket gophers and browsing by deer and elk, resulting from reliance on the alternative of mechanical weed control and its subsequent stimulation of forb cover habitat.

Although one can enumerate acreages of herbicide use to control these weeds and costs of reducing weed losses, it is easy to overstate or understate actual losses. For example, it might be shown that hardwoods occupy much of the productoverstate or understate actual losses. For example, it might be shown that hardwoods occupy much of the productive conifer forestland in the lower 48 states, hence the loss would be the equivalent difference in value between hardwoods and conifers on these sites. In the absence of management plans on roughly half of the commercial forestland in small ownerships, it is not likely that such values have much meaning. Moreover, the use of a herbicide is a portion of a larger management system that includes nursery production, tree planting, site preparation, thinning, and other weeding operations. The exact

There is also the factor of tool availability. In 1960, phenoxy herbicides were used for most of the hardwood and shrub problems in the United States, and at that time made the difference between economic management and non-management on a regional scale. In the absence of other herbicides, the phenoxy herbicides were able to do an adequate job, but now they have been replaced by more specific or effective herbicides for many uses. At the time of their prevailing use, it was not anticipated that values of stumpage revenue would rise by a factor of 20 in 30 years. At that time, calculations of their value substantially understated their economic impact on harvests of valuable timber in the 1990's.

If alternative herbicides were not available today, phenoxy herbicides would be far more crucial to forestry than a current analysis of all available technology will indicate. Of course, there are no guarantees of future availability of any production tool subject to regulatory action; so the time frame of the forestry picture dictates inclusion of a scenario and time when other broadleaf weed killers are not available. This might be characterized as the ultimate societal cost associated with loss of the resource. This does occur with the loss of diclorprop for release of ponderosa pine.

Value systems are also changing on a major scale, and these fluctuate so rapidly that long-term projections are virtually impossible. For example, between 1950 and 1983, the USDA Forest Service had active research and development programs in forest vegetation management, of which 2,4-D was an important component. In 1983, the USDA Forest Service was enjoined from using herbicides in any way by injunctions triggered by the failure to prepare adequate environmental impact statements (EIS) as required by the National Environmental Policy Act. After 10 years without herbicides, the USDA Forest Service now has an acceptable EIS, but uses herbicides very little, because its focus has shifted away from timber production toward amenity values. This extends across the third of forest land in the United States that is managed by the USDA Forest Service.

Some examples can be given with certain assumption sets that help provide perspective on loss potential. We will discuss a state agency, a private landowner, and a timber-producing corporation for three scenarios. These scenarios are common in the Pacific Northwest, where the most 2,4-D is used on forestland, and on sites of average productivity for Douglas fir. In all cases, owners will be assumed to have the objective of producing commercial crops of coniferous timber, primarily Douglas fir in the Pacific Northwest. Also included are Christmas tree production, another minor but valuable cropping system involving forest weed control.

State of Oregon ownership. Most of Oregon's state ownership of forest land is in the highly productive Coast Range, where the principal target weed is red alder. In this ownership, land productivity averages 200 cubic feet/A or 1,000 Mbf/A/yr, capable of accumulating a value of roughly $50,000/A in a 70-year cycle, of which roughly a third accrues from intermediate harvest (thinnings and salvage) with intensive management. State policies focus on certain amenity values that reduce total area subject to intensive management, but do permit use of herbicides on available intensively managed lands. These lands may differ principally on length of harvest cycle, with longer cycles leading to somewhat reduced growth rates and substantially higher discount cost.

On intensively managed lands, losses from red alder and other broadleaf woody species range from 10% to total failure, including complete loss of the investment in planting stock and labor, which averages some $175/A. These lands remain essentially out of production indefinitely, or until a crop of alder is harvested, followed by replanting to Douglas fir, and then risking their establishment failure once more. What makes this scenario so difficult to evaluate is that Douglas fir is normally planted at a density of some 300, or more, trees/A. There is general agreement that losses from stocking levels below 150 trees/A are unacceptable and require interplanting. Oregon law now requires the establishment and protection of at least 200 seedlings/A following harvest. Yet 50 trees/A will, at 100 years, have almost the same yield potential as 200 trees (8), apart from early thinning revenue and opportunity for enhanced early yields.

The productive coastal sites represent a negative PNV of $175/A (based on expected discounted cost of taxes for an extended period without income), if a plantation completely fails, plus the present value of a discounted harvest of red alder. If red alder were expected to bring a return of $500/A in 1994 dollars 40 years hence, its present value would be $104/A at a real rate of return of 4% above inflation. Thus, the present value in the worst case of -$175 + $104 = -$70, a present liability, or negative PNV.

In the best case, the future value is the discounted value of the Douglas fir yield minus establishment and maintenance costs. For example, Douglas fir can be planted at a cost of $175/A, released with herbicides after 3 years, spaced after 12 years (cost of $80/A), commercially thinned after 35 years (5 Mbf at $400/Mbf), and 45 years (5 Mbf/A at $500/Mbf) with a final harvest at 60 years of 50 Mbf/A at $700/Mbf. Thus, the contribution to PNV is shown in Table 2.

Table 2. Estimated management costs and revenue contributions to present net value of Douglas fir forestland in Oregon during 1992.

Timber management	Years	Discount factor	PNV in $/A
Planting cost of $175/A	0	0.00	-175
Spacing cost of $80/A	12	1.60	-50
Harvest returns			
5 Mbf/A at $400/Mbf	35	3.95	507
5 Mbf/A at $500/Mbf	45	5.84	428
50 Mbf/A at $700/Mbf	60	10.52	3,327
Present net value (without consideration of weeding costs) =			$4,037

The difference in timber value between worst and best management is (-$71/A vs. $4,037/A) or $4,108/A without consideration of weeding costs. Various possible weeding costs are considered in the following discussion.

If 2,4-D alone is used to achieve weed management, some weed species will probably not be controlled adequately. Salmonberry, elderberry, and vine maple are usually present where red alder is the dominant weed. Thus, data precise enough to evaluate the yield difference between the best weed control (hexazinone initially followed by glyphosate at year 2) and 2,4-D alone are not available. It is estimated that 2,4-D alone at age 2 would have the same range of yield as the "best" yielding prescription, but average about 10% less, with the major loss being the loss of the thinning at age 35, with its contribution of PNV being $507/A.

If the PNV is based on a yield of $4,037/A minus two weedings, with hexazinone at year 0 ($64/A) and glyphosate at year 2 (cost of $28/A), PNV would be $3,945/A. PNV with 2,4-D at year 2 (cost of $22/A) would reflect loss of 35-year thinnings ($507) and cost of applying 2,4-D (cost of $20) so that PNV would be $4,037/A minus ($20 + $507) = $3,510, a difference of $435/A in favor of the alternative to 2,4-D.

If red alder were the only major weed present and 2,4-D controlled it completely so as to give maximum yield, reliance on 2,4-D would save $80/A. But if red alder were the only significant target weed, triclopyr would probably be the alternative herbicide of choice in the absence of

2,4-D, at a discounted cost (projected future need) of $44/A. In this case, a cost of $24/A would be encountered from not having 2,4-D. Assuming that, of the total acreage sprayed on state of Oregon land, some 500 A/yr would be exclusively in the 2,4-D sensitive target species, the annual net benefit from 2,4-D for broadcast application would be $12,020. This small sum is the result simply of small areas of state land, coupled with total specification of limits of 2,4-D suitability. Thus, the increase in PNV on State of Oregon land would be based on the formula:

<u>Savings/year</u> = change in PNV

4% (interest)

=$12,020 /0.04 = $300,500 as the net societal value of retaining 2,4-D based on product costs for alternatives at 4% real interest rate.

The reality is that 2,4-D is used on much more than 500 acres of state lands annually, in tank mixes with atrazine, triclopyr and picloram. Thus, the above is an analysis of a minor use, but one for which value can be calculated with precision.

Oregon, industrial ownership. These lands are of the same quality and have the same general problems as state lands, but differ slightly in management strategy. They differ in having a much larger area of sites where red alder is a primary target species, and a much larger area on which tank mixes are used. An important addition to red alder among species uniquely sensitive to 2,4-D and diclorprop are madrone, ceanothus, and manzanita. On lands with these species, alternative chemicals are not available that are both selective and effective, hence the value of phenoxy herbicides is absolute.

Industrial lands similar to State lands tend toward shorter rotations and less emphasis on commercial thinning. With an anticipated yield of 50 Mbf/A at 50 years resulting from planting, spacing, two herbicide applications, final harvest, and costs as on state lands, the PNV of each component is shown in Table 3.

Table 3. Estimated management costs and revenue contributions to present net value of Douglas fir forestland in western Oregon and Washington during 1992.

Forest management	Years	Discount factor	PNV $/A
Planting cost of $175/A	0	0.00	-175
Release cost of $22/A	2	1.08	-20
Spacing cost of $80/A	12	1.60	-50
Early harvest	5	7.11	4,925
Final harvest	52	7.69	4,553

In this instance, the difference between yields from release by glyphosate and hexazinone versus 2,4-D alone may be expressed in terms of delayed yield. Thus, for most weeding needs, the more expensive treatment is cost-effective. However, on about 5,000 A/yr, 2,4-D remains able to handle nearly pure red alder where resistant species do not create future problems when only red alder is controlled. On such areas, there is a net savings of $24/A x 5,000 = $120,000 per year.

On sites where manzanita, madrone, and ceanothus are prevalent, manzanita and madrone are controlled poorly by triclopyr, the usual substitute for phenoxy herbicides. Approximately 10,000 A/yr are sprayed in such sites with 2,4-D, with or without atrazine, for simultaneous grass control. These sites are expected to yield some 30 Mbf/A in 80 years with weed control, and 20 Mbf/A in 100 years with manual weeding or 15 Mbf/A at 100 years without weed control. Without the herbicides, planting costs will have to allow for one or more interplantings to compensate for mortality from weeds. Forest management using different planting times, non-chemical alternatives, costs per acre, benefits, and PNV are shown in Table 4.

Table 4. Estimated management costs and revenue contributions to present net value of poor forestland in southwestern Oregon and Northern California during 1992.

Forest management	Years	Discount factor	PNV in $/A
Planting cost of $175/A	0	0.00	-175
Spray 2,4-D + atrazine	0	0.00	-29
Second planting	2	1.08	-162
Planting at $100/A	4	1.17	-85
Manual release at $90/A	6	1.26	-71
Thin, 5 Mbf/A at $500/Mbf	45	5.84	428
Final cut, 30 Mbf/A at $700/Mbf	70	15.57	1379
Final cut, 20 Mbf/A at $700/Mbf	100	50.50	416
Final cut, 15 Mbf/A at $700/Mbf	100	50.50	208

With these data, investment in planting and spraying with 2,4-D and atrazine ($204) yields a PNV of $1379 + $416, or a net yield of $1795/A. Without 2,4-D and atrazine, the yield would be $416 - 422 (plantings) -$71 = -$77/A, a negative value, hence a liability. The yield with no weed control would be too low to justify the investment in planting, yet reforestation is required by law in Oregon and all other Pacific Coast State. Thus, the loss of the primary weed control tool 2,4-D is a major problem that jeopardizes the timber resource. Manual release and site preparation have not been demonstrably effective. Expanded to the entire annual treatment area, 10,000 A/yr, the difference between PNV's with and without herbicides is $1457/A x 10,000 = $14,570,000 per year. The present value of a perpetual series of increases in PNV at this rate equals: $14,570,000 /0.04 = $364,250,000 as a net societal value over years for the Oregon timber industry alone.

The above figure differs from situations in which alternatives are available, in that the treatment is uniquely adapted to restoring the entire value of the resource. Thus, the value is much higher than would be the case where the simple cost is that of changing products. But it is an annual loss of net worth, hence an annual cost.

Oregon small woodland owners. This ownership is concentrated on highly productive sites at low elevations. Besides red alder, Scotch broom and broadleaf herbs are serious problems for which 2,4-D is well suited. These sites also support the high profit Christmas tree industry.

Small woodland owners normally own lands with long histories of exploitive management, despite the rapidly improving management technology in recent years. Because of this, they seldom have simple brush problems suitable for treatment with a single product. Their lands are more similar to State owned lands than to industrial ownerships, being at low elevations on productive sites, and reflective of the same past problems that brought many of them into State ownership at tax sales 50 to 60 years ago. Thus, programs of glyphosate and hexazinone for site preparation, followed by glyphosate for release, are the most effective treatments.

The small woodland owner is not as likely to pursue maximum yields as is the industrial owner if it requires a high initial investment to do so. So the woodland owner faced with a brush problem will often use 2,4-D simply because it is cheaper, and the owner will likely not be the individual most likely to reap the return on that investment. Thus, a substantial acreage will be sprayed with 2,4-D alone under circumstances where the alternative may be no weed control. Approximately 10% of all small woodland cuttings are followed by inadequate reforestation, with brush cover being the most common factor (9). Many of those that are sprayed are treated with 2,4-D in combination with atrazine before planting or for conifer release. However, with some 2.8 million acres in small woodlands, and 1.6% being harvested by clear cutting per year, some 45,000 acres are cut. If 5% of that (i.e., 2250 acres) were not satisfactorily restocked because of not using 2,4-D, and the loss in PNV were 50%, the per-acre value loss would be as shown in Table 5.

Table 5. Estimated management costs and revenue contributions to present net value of small woodlands in western Oregon during 1992.

Forest management	Years	Discount factor	PNV in $/A
Planting cost of $175/A	0	0.00	-175
2,4-D + atrazine at $35/Aa	0	0.00	-35
Thinning 5 Mbf/A at $400/Mbf	30	3.24	617
Thinning 8 Mbf/A at $600/Mbf	45	5.84	822
Final cut 45 Mbf/A at $700/Mbf	65	12.80	2461
Final cut 29 Mbf/A at $700/Mbf	65	12.80	1586

[a] Note that the higher unit cost is due to small scale use.

The woodland owner who sprays and thins on land subject to trouble with 2,4-D- sensitive brush has a PNV potential of harvest value per acre of $3900 -$210, or $3690; whereas, the owner who settles for half a yield without herbicides, all of which is at rotation age, has a PNV of $1586 - $175 = $1411, a difference of $2279/A. Expanded to 2250 A/yr, the cost of not having the herbicide treatment would be $5,127,750/yr, with an impact on PNV of $128,194,000.

Actually, the above calculations are legitimate for owners who hold the land for a rotation, but the average turnover is much more frequent. There is an increasing trend for lands in poor shape to be purchased by timber companies and rehabilitated. Thus, although the cost to the long-term owner may be $2279/A, there is a good chance that this owner will use appropriate technology, and not opt for the low-cost alternative as a sole instrument for weeding. Rather, if 2,4-D were not available, an alternative of higher cost would apply. In this case, his scenario would be similar to that of State owned lands, with a cost of $24/A treated, a total of $54,090/yr, based on adequate alternatives. But the total cost of not having 2,4-D remains conjectural. At $54,090/yr /0.04, the net societal value is

$1,352,250 for having 2,4-D in Oregon alone.

Christmas trees. There are approximately 100,000 acres of Christmas trees on small woodland holdings in Oregon. These are treated annually with herbicides in order to keep quality and production levels high. Market penetration of this technology is nearly 100%. These growers rely on Douglas fir for some 90% of total production, and this provides an opportunity to use 2,4-D broadcast and selectively whenever broadleaf weed problems appear.

There are no formal estimates of total 2,4-D use in Oregon Christmas tree production. However a reasonable estimate would be that 2,4-D is used at least once in every 7-year production cycle on a quarter of all Christmas tree acreage in the Pacific Northwest. Thus, if the alternative to 2,4-D is a directed spray with glyphosate, at $60/A, versus $19/A with 2,4-D, the difference of $41/A would occur on 90,000 A/7 yr = 12,857 acres divided by 4, for a total of $131,786/yr difference in operating cost. If the weeds were not controlled, sharp losses in quality would occur, and financial losses would be measured in terms of percentages of downgraded trees at harvest. Although no estimates are available of degree of downgraded trees from not controlling weeds, the competitive situation in Christmas trees today is so intense that net sales would be very much reduced if the average grade were reduced even one level. Current prices for grades 1 and 2 Douglas fir differ by about $2 per tree. At a level of production of 1400/A/7 yr, or 200/A/yr, lack of broadleaf weeding would cause a loss of some $400/A/yr. On 90,000 acres, this amounts to an economic loss of $36 million/yr. The actual loss would likely be somewhat less because of market shifts. Oregon produces such a large portion of total available trees that there would be some price compensation. Moreover, not all trees would be downgraded. Thus, the above figure represents a worst case scenario.

Despite the above calculations, the actual value of 2,4-D to Christmas tree growers may have to be determined more subjectively. Virtually every grower has a supply of 2,4-D on hand. It is used when 2,4-D can control the weed better than an alternative. Christmas tree culture is extremely intensive, and growers will avoid allowing problem weeds to become established if at all possible. Many growers selectively spray their plantations with 2,4-D in backpack sprayers in June, to prevent spread of St. Johnswart or tansy ragwart, noxious weeds that are resistant to residual herbicides, or glyphosate. Because these growers are mostly independent farmers, their purchases of herbicides may come from any source, and use estimates miss market surveys that attempt to document consumption by various uses. Thus, the figure of a quarter of the acreage being treated broadcast each 7 years, plus spot treatments periodically, represents an estimate of Christmas tree usage that is close to reality. In Oregon, this would amount to some 10,000 lb/yr. Expansion to Washington and northern California would likely double that quantity to 20,000 lb/yr for western Christmas tree production.

Assuming that triclopyr would be the product of choice if one had to substitute for all uses of 2,4-D, and that the rate of use would be half that of 2,4-D, the annual value of 2,4-D to growers would be the value of the substitute used minus the cost of 2,4-D, or 10,000 x $22 minus 20,000 x $2.50 =$170,000/yr.

CURRENT CONTROL METHODS

The phenoxy herbicides are part of a small but effective package of herbicides used for enhancing forest composition and timber yield. In this group are, in order of quantity used, glyphosate, hexazinone, triclopyr, imazapyr, atrazine, 2,4-D, picloram, diclorprop, and several herbicides that are registered for limited use in a specific local area under a provision of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). Most are applied by air in all western regions where chemical weed control is large in scale. In the South, skidder-mounted broadcast spraying systems equipped with boomless nozzles are also in extensive use.

The two major uses of 2,4-D are control of red alder in the Pacific Northwest for aerial release of Douglas fir and western hemlock, and control of evergreen shrubs in Southwestern Oregon and Northern California. In the latter situation, uses include site preparation where ponderosa pine is to be planted, and for Douglas fir release. There is a modest level of use distributed over a large number of acres wherein 2,4-D amine is mixed with picloram for trunk injection to remove large cull hardwoods.

Diclorprop is a specialty product that is used for selective control of evergreen shrubs in ponderosa pine plantations. It is currently not adequately substituted for by any other compound. Diclorprop is non-injurious to ponderosa pine at rates that control greenleaf and whiteleaf manzanitas, madrone, and ceanothus species. These are major competitors that are susceptible to other herbicides, all of which are injurious to pines. Thus, loss of diclorprop leaves only the alternative of hand clearing of shrubs, a process providing demonstrably poor efficacy.

[2] Newton, M. and M. Capo. Unpublished data. Oregon State Univ., Corvallis, OR 97331.

When phenoxy herbicides are used for shrub control, they are sometimes mixed with soil residual herbicides such as atrazine or hexazinone to prevent forbs and brush from preempting the resources released. This combination is unworkable without the broadleaf control effected by the phenoxy herbicides.

COST OF CURRENT CONTROL METHODS

All control methods applied by air have the same fixed cost of aerial application. The cost of application is for 5 to 10 gallons per acre of carrier, and costs range from about $12 to $20/A. The cost of herbicides and application for broadleaf weed control is listed in Table 6 (examples from Pacific Northwest sales) on a dollar-per-acre basis.

Table 6. Estimated weed management costs of forestland with various herbicides in the United States during 1992.

	Rate	Average cost	Total cost[a]
Herbicide	lb/A	$/lb	$/A
2,4-D ester[b]	1-2	3.33	15-27
Atrazine[b]	3-4	3.00	21-32
Diclorprop	2.0	7.50	27-35
Glyphosate[b]	0.75-1.5	21.00	28-51
Hexazinone[b]	1-2	26.00	38-72
Imazapyr	0.062-0.25	95.00	17-44
Metsulfuron	0.036	807.47	41-49
Oxyfluorfen[c]	0.75-1.25	54.66	53-89
Sulfometuron[b]	0.092-0.133	180.80	29-44
Triclopyr[b]	1-1.5	20.00	32-50

[a] Total cost includes expected cost of application by aircraft of $12 to $20/A.

[b] Products used in Christmas trees and reforestation.

[c] Products used for Christmas trees only.

The preceding table lists total application and product costs for various products and uses. In many cases, tank mixtures may be applied at the lower rates of any given product, in which case the combined costs of the lower rates, plus one application cost, equals a net cost per acre. Not listed in the table is the cost of hand release of conifers, which ranges from $50 to $175/A, depending on infestation conditions and distance from a labor source.

PROSPECTIVE USES OF PHENOXY HERBICIDES IN FORESTS

Recent values of timber have focused increasing attention on the ponderosa pine lands east of the Cascade and Sierra Mountains. These areas have had a history of high-grade harvesting and inadequate regeneration. These sites often support evergreen shrub stands that are almost totally inhibitory to conifer regeneration. Manzanitas, madrone, golden chinkapin, and ceanothus species are hardy shrubs that have taken over many sites that have the capability of growing commercially attractive yields of timber. At this time, the only products known to be broadly effective for the control of these shrub-mixtures are 2,4-D and diclorprop. Diclorprop also is selective on pine species, hence it represents a major opportunity for increasing pine yields.

The intensity of potential use of phenoxy herbicides in the pine region is not limited by sensitive crops because that is not an intensive crop growing region, apart from distant wheat farms, where 2,4-D is in regular usage. The importance of phenoxy herbicides in the future of this resource may be much greater than in other regions because of the lack of alternatives. However, value cannot be claimed at this time because of the current low rate of use and non-registration of diclorprop in California. Nevertheless, this region is the site of some of the most crucial forest health issues in this country, and tree species composition and stand stocking have been decimated by repeated insect attacks. The insect attacks are often attributed to tree stands that have been poorly managed, with improper attention to species composition and stand density. Having adequate tools for achieving stand management targets in forests is an important consideration for maintaining registrations of both 2,4-D and diclorprop.

Phenoxy herbicides have also been shown to assist in environmental control of damaging rodent populations in forests. When 2,4-D is mixed with a grass herbicide, such as atrazine or hexazinone, the control of broadleaf weeds impoverishes the habitat for pocket gophers. These rodents are limiting to reforestation areas. Rodent populations are increased by mechanical scarification with brushrakes because of increased encroachment of fleshy-rooted forbs and loosened soil. Thus, the use of broadleaf weed control offers a major opportunity to avoid the use of toxic baits for rodent control (2) while providing growth benefits to trees because of better weed control.

TOTAL FORESTRY USE

Market surveys place total annual use in the Pacific Northwest and California at approximately 120,000 pounds of 2,4-D and 2,000 pounds of diclorprop. Usage of 2,4-D in the Northeast and South appears to have diminished sharply in recent years with the advent of hexazinone, imazapyr, glyphosate, and triclopyr. These herbicides are all more costly, but achieve a more effective result. Because of the increase in price of timber, growers are less willing to rely solely on a product that kills such a narrow-spectrum of broadleaf woody species as do the phenoxy herbicides. In the South, Dr. G. J. Gjerstad, of Auburn University places use level at about 40,000 acres treated with all phenoxy herbicides, with about 68,000 pounds of 2,4-D used (unpublished estimate). The NAPIAP survey indicated that diclorprop use was only 10,000 pounds annually. In the Northeast and Lake States, there is an estimated annual total 2,4-D use on 10,000 acres with 20,000 pounds of chemical, but with no diclorprop use. Thus, nationwide, including all uses for tree injection as part of a picloram mixture, Christmas trees, spot treatments, and components of larger tank mixes, an estimate of 228,000 pounds of 2,4-D and 12,000 pounds of diclorprop used annually appears reasonable. This is applied on roughly 0.04% of all commercial forest land in the United States, or 0.2% annually of land managed for high timber yields (Table 7).

Table 7. Estimated use of phenoxy herbicides in forestland and on Christmas trees in the United States during 1992.

Herbicide	Region	Use	Treated acres	Pounds used
2-4,D	Pacific Northwest	Site prep & release	60,000	120,000
		Christmas trees		20,000
	Southeast	Tree injection	63,000	68,000
		Site prep		
	Northeast	Conifer release	10,000	20,000
Diclorprop	Pacific Northwest	Pine release	1,000	2,000
	Southeast	Pine release	5,000	10,000
Total				240,000

PNV projections of timber valuation into perpetuity attributed to the use of phenoxy herbicides. Because of the low frequency of usage of a herbicide on any unit of forest land, followed by a long period of multiple-year benefits, a low rate of usage eventually contributes to the increased management of a lafrequency of usage of a herbicide on any unit of forest land, followed by a long period of multiple-year benefits, a low rate of usage eventually contributes to the increased management of a larger area. If a landowner uses a product on 2% of any given ownership each year, 50 years of management and low-intensity use will eventually expand effects to the entire ownership and increase productivity on all of it. On this basis, one may es

Estimated contributions of phenoxy herbicides to forest operations nationally assumes that 2 million acres of Pacific Northwestern land will eventually be treated in some way with a phenoxy herbicide, 7.5 million acres of southern pine, and 0.5 million acres of northern woodlots. Thus, the following timber values are shown in Table 8.

Table 8. Estimated increase in value of timber because of the use of phenoxy herbicides in the United States during 1992.

Region of the United States	Increased value of timber due to weed control	Acres treated	Portion contributed by phenoxy herbicides	Value contributed by phenoxy herbicides
	$/A/yr	(000)	%	$/yr
North	40	500	5	1,000,000
South	185	7,500	2	27,750,000
West	350	2,000	1	7,000,000
Total				35,750,000

The total value of annual increases in harvestable timber value attributable to phenoxy herbicide use is $35,750,000. This total represents the national sum of all increased productivity and value contributed by the phenoxy herbicide component of complex management systems applied during the rotation. At a real rate of return of 4%, the continued registration of phenoxy herbicides, and of 2,4-D in particular, represents a net societal value, expressed as an increase in PNV of:

$\frac{\$35,750,000}{0.04}$ = $893,750,000 as the total net societal value for timber over years.

Added to this would be $4.25 million for the present value of Christmas tree uses. Thus, the total PNV of the timber and Christmas tree added by availability of phenoxy herbicides is $898,000,000 over the entire growth period of the timber species.

Estimated net impact of banning phenoxy herbicides in forestland. The annual cost of operation without phenoxy herbicides is of two types, the extra cost of other products, where available, and the loss of resource value where no alternatives are available. For 2,4-D, the average increase in cost of alternatives is about $24/A. Based on 110,000 acres treated with 2,4-D nationally, this expands to an additional total annual operating cost of $2,644,400. For the 10,000 acres for which no substitutes for 2,4-D are available, a loss of resource value amounting to $1,456/A would occur, for a total annual loss of about $14,560,000. For the loss of diclorprop, the cost would be based on 1,000 acres of lost resource in ponderosa pine forests at about $500/A, or $500,000/yr. Loss of diclorprop in the South on 5,000 acres would mostly be substituted by triclopyr, at a cost of roughly $21/A, or $105,000/yr. Thus, the total increased costs from not using 2,4-D would be $17,204,400, and for diclorprop, $605,000 per year for a total of $17,809,400 annually.

There is an acknowledged uncertainty in estimates of the specific uses of phenoxy herbicides and their contributions to the total value of forest products annually or over many years. The fact that more intensive use of other management inputs, and use of substitute products, may negate some of their value, the above figure represents a reasonable approximation of the contributions made by phenoxy herbicides in 1992, provided their use were to continue for 50 or more years. In view of five decades of phenoxy herbicide use, and their continued use worldwide, the future use of these herbicides is probably more assured than many other forestland management practices. Even if estimates were off 20%, the current value of registration for phenoxy herbicides is still substantial, simply because of the areas responding to usage in previous years, hence their cumulative effects.

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Figure 1. Helicopter application of 2,4-D at 2 lb/A in April 1965 for the control of red cedar and other broadleaf trees and shrubs in order to release Douglas fir along the Coast Forest Range of Oregon. Aerial application is the predominant method of using phenoxy herbicides in forestry for the release of conifers. (Photograph by the author).

Chapter 12

Assessment of 2,4-D Use in Aquatic Systems in the United States

CAROLE A. LEMBI [1]

Abstract. Aquatic weed infestations reduce the use of water for recreation, navigation, irrigation, aquaculture, and potable water. The invasion of exotic aquatic weed species such as waterhyacinth, Eurasian watermilfoil, and purple loosestrife into our nation's inland waters and wetlands has greatly decreased the diversity of native aquatic plant species with concomitant adverse effects on fish and other animal life. Federal and state agency personnel were surveyed regarding acreages of waterways infested with exotic weed species and their use of 2,4-D, it being the only phenoxy herbicide registered for use in aquatic systems. Use of 2,4-D is currently the most cost-effective method for suppressing the growth of these invasive species. Estimated average costs of using 2,4-D ranged from $5/A (herbicide only) and $65/A (labor and herbicide) for waterhyacinth control to $171/A (herbicide only) and $319/A (labor and herbicide) for Eurasian watermilfoil control, for which granular 2,4-D is used. If alternative herbicides had to be used, expenditure for just the chemicals alone would increase to as much as $74 per acre for waterhyacinth control and $245 per acre for Eurasian watermilfoil control, thus boosting combined labor and herbicide costs significantly over present costs. The estimated total cost of alternative herbicides to control aquatic weed infestations if 2,4-D were lost is approximately $19.4 million, as compared with the $2.8 million that was spent to purchase 2,4-D for aquatic weed control in 1993. Thus, the net societal cost of losing 2,4-D for aquatic weed management in the United States would be $16.60 million annually. Because many non-target aquatic and ditchbank plants are monocots, the use of 2,4-D permits these species to survive and in some cases revegetate treated areas, which reduces soil erosion. Non-chemical control methods (e.g. biological and mechanical control) have been relatively ineffective in alleviating the impact of exotic species on native plant populations. Because of its excellent record of safety to applicators, the general public, and the environment; its efficacy in controlling some of our most invasive and noxious aquatic weed species; and its cost-effectiveness, 2,4-D should be retained for use in aquatic systems.

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INTRODUCTION

In 1992, approximately 400,000 surface acres of water or wetlands were treated with herbicides to control aquatic weeds in the United States. This area is less than 0.8% of the total inland water surface area. However, even though the treated area is small, the problems that aquatic weeds cause, if left untreated, are enormous. Aquatic weeds block water flow in both irrigation and drainage systems. Severe infestations prevent the use of water for recreational activities such as swimming, fishing, boating, and water skiing and have even been known to entangle swimmers, causing drownings. Excessive weed growth leads to an imbalance of fish populations in natural systems and prevents the harvest of fish and other marketable aquatic life in aquaculture and hatchery production systems. The die-off and decomposition of weeds and algae results in oxygen depletion in the water, which can cause stress and even death of fish and other aquatic life. Invasive weed species such as Eurasian watermilfoil, waterhyacinth, and hydrilla take over aquatic communities. By reducing populations of native aquatic plant species, these weeds decrease diversity of both the plant and animal life. Aquatic vegetation provides habitat for the development of harmful insects such as mosquitos, and to many people, aquatic plants are unsightly and can cause significant depreciation of waterside property values.

Because of the variety of problems caused by aquatic vegetation, and the fact that it is difficult to place a monetary value on water in a recreational or natural setting, the exact dollar loss resulting from aquatic weed infestations is difficult to compute, and thus it is underestimated. One way of estimating dollar losses from aquatic weeds is from the sale of aquatic herbicides, which amounted to $19.3 million in 1992 in the United States. Additional cost is incurred from the use of other aquatic management strategies such as mechanical harvesting, biological controls, and the reduction of nutrient inputs into water via installation of sewer systems and water treatment facilities.

The leading users of aquatic herbicides are government agencies, both federal and state. The three major federal users of herbicides are the United States Army Corps of Engineers, the Bureau of Reclamation, and the Tennessee Valley Authority (TVA). These agencies and selected state agencies (data obtained for California, Florida, Georgia, Louisiana, Minnesota, Texas, and Wisconsin) were surveyed regarding acreage infested with aquatic weeds and their use of 2,4-D.

A copy of the survey questionnaire is included as Appendix 12-1 to this chapter. Private users include commercial applicators, individuals, and organizations. Information on 2,4-D use from private entities is difficult to obtain, but the survey results from federal and state agencies should reflect weed management experiences but not 2,4-D use data of private applicators.

PHENOXY HERBICIDE REGISTRATION SUMMARY

The only phenoxy herbicide registered for use in aquatic environments is 2,4-D. One of the major 2,4-D products registered for use in aquatic systems is a 27.6% acid equivalent (a.e.) granular formulation of the butoxyethyl ester of 2,4-D. This product is used primarily for the control of the submersed weed Eurasian watermilfoil. The other major 2,4-D product used in or around aquatic sites is the dimethylamine salt (48.6% a.e.) of 2,4-D. This liquid product is primarily used for control of the free-floating aquatic weed, waterhyacinth, but it is also cleared for brush control along ditchbanks. As specified on the herbicide label, TVA is the only agency that can use this 2,4-D formulation in water for the control of Eurasian watermilfoil. The 34.05% a.e. triisopropanolamine salt of 2,4-D is also labelled for use on broadleaf weeds along drainage ditch banks. A few of the liquid 2,4-D ester formulations are cleared for use along drainage ditchbanks, but they are not supposed to come into contact with the water because of possible toxicity to fish and other aquatic organisms.

LOSSES DUE TO BROADLEAF WEEDS

The major weed targets for 2,4-D use in aquatic systems are waterhyacinth, Eurasian watermilfoil, and emergent species along ditchbanks. Among the latter are bulrushes and cattails, both monocots, as is waterhyacinth. Therefore, the common belief that 2,4-D is specific for the control of broadleaf plants (dicots) is not always true. Nevertheless, 2,4-D is useful on ditchbanks because it can selectively remove broadleaf weedditchbanks. Among the latter are bulrushes and cattails, both monocots, as is waterhya

Waterhyacinth is limited to the Southeastern United States and some portions of California. In Florida's public lakes and rivers, 35,609 acres of waterhyacinth (and waterlettuce) were controlled in 1991 to 1992 at an expense of $2,871,649 to federal, state, and local agencies (2). Most of this expense was undoubtedly for 2,4-D, because it is the major herbicide (and the cheapest) used for waterhyacinth control. The Army Corps of Engineers alone treated 17,550 acres with 2,4-D in 1993 in Florida. In Louisiana, with a total water area of 2.7 million acres, approximately 400,000 acres (15% of the total) are infested with waterhyacinth. The Army Corps of Engineers reported that 40,000 acres of waterhyacinth (10%) were treated with 2,4-D in Louisiana in 1993.

Eurasian watermilfoil is the major weed problem in the TVA management system where, out of 474,800 managed acres, 1,400 are treated with 2,4-D. Outside of the TVA area of responsibility, Eurasian watermilfoil is a major weed in the Northern States, from Vermont to Washington, and in Canada. Eurasian watermilfoil is an exotic species to the United States and is extremely invasive in aquatic habitats. Within the last 10 years it has been found in Minnesota where a concerted, but losing, effort is being made to prevent its spread from the urban lakes of Minneapolis to over 10,000 recreational lakes in other parts of the state. Currently, more than 3,000 acres of water per year are treated with 2,4-D in Minnesota in order to reduce the spread of Eurasian watermilfoil.

Data on ditchbank weed control are difficult to obtain because they are often considered with rights-of-way and noncropland treatments. Control on ditchbanks includes not only true aquatic emergent species such as cattails, willows, purple loosestrife, and buttonbush but also terrestrial species that happen to be growing close to water. For example, in the South Columbia Basin Irrigation District of Washington, 1,800 acres of canals and ditchbanks were treated with 2,4-D in 1993 for the control of such broadleaf weeds as Canada thistle, common cocklebur, curly dock, kochia, Russian thistle, and other terrestrial vegetation.

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CURRENT CONTROL METHODS

Current control methods for aquatic weeds include a variety of approaches such as mechanical, biological, and chemical. Mechanical control methods range from harvesting by machine to raking aquatic weeds by hand. Biological controls include waterfowl (primarily ducks, geese, and swans) and herbivorous fish such as the grass carp that has been introduced into many states. Dyes or opaque plastic that prevent light penetration to the bottom-growing vegetation are used primarily in ornamental and golf course ponds. Herbicides that are labelled for aquatic use on flowering plants are fluridone, diquat, endothall, glyphosate, and 2,4-D. All of these, except glyphosate, are labelled for Eurasian watermilfoil control. Diquat, glyphosate, and 2,4-D are labelled for waterhyacinth control and ditchbank weed control.

Most of the 2,4-D applied for waterhyacinth and Eurasian watermilfoil control is via surface (boat) application; however, aerial spraying of waterhyacinth was reported in Florida and Texas, and the Nashville district of thespraying of waterhyacinth was reported in Florida and Texas, and the Nashville district of the Army Corps of Engineers reported aerial spraying of small acreages of Eurasian watermilfoil. Ditchbank weeds were mostly treated usi

COST OF CONTROL METHODS

In 1993, total sales of aquatic herbicides in the United States was approximately $19.3 million. Of that amount, 14% or $2.8 million was 2,4-D sales. This dollar value is deceptive in terms of how much 2,4-D product was used because, as compared with other aquatic herbicides, 2,4-D is relatively inexpensive. More 2,4-D was used in 1993 than all other aquatic herbicides combined; 2,4-D accounted for 66% of the total pounds of active ingredient that were sold for aquatic weed control and for 56% of the total aquatic acreage treated.

In the user survey, both herbicide and application costs were estimated and are presented in this chapter. Costs varied depending on the 2,4-D formulation used. In states where Eurasian watermilfoil was treated with granular 2,4-D, the cost for product plus labor and equipment was approximately $319/A. In the TVA system, which is allowed to use the lowest cost liquid 2,4-D formulations for Eurasian watermilfoil control, treatment cost averaged only $112/A. There is considerable interest among state agencies to obtain regulatory permission to use liquid 2,4-D formulations for Eurasian watermilfoil control because this would significantly reduce their costs and hence the financial burden on taxpayers.

Application cost for waterhyacinth control with liquid 2,4-D formulations was also relatively inexpensive at $65/A. Ditchbank treatments ranged from $15 to $45/A.

Among the agencies surveyed, a total of 4,652 acres (3,252 acres with granular 2,4-D and 1,400 acres with liquid 2,4-D) was treated in 1993 for Eurasian watermilfoil control at a total cost of $1,195,500. For waterhyacinth, 97,789 acres were treated at a total cost of $9,514,900. Thus, the annual cost (for materials and labor) to federal and selected state agencies for waterhyacinth and Eurasian watermilfoil control totalled more than $10,000,000. Because the total gallons and pounds of 2,4-D used by these agencies accounted for approximately 30% of the total amount of 2,4-D sold in the United States for aquatic weed control in 1993, an estimate of the cost to users for aquatic weed control with 2,4-D is approximately $33 million per year.

WEED CONTROL ALTERNATIVES IF 2,4-D WERE LOST

If 2,4-D were lost, other herbicides could only partially take its place, and they would be more expensive. Agency estimates for substitution of fluridone treatment for Eurasian watermilfoil control averaged $565/A (for materials and labor). Endothall would likewise cost a total of $565/A, and diquat treatments would cost $300/A. Of these, diquat appears to be the most cost-competitive with 2,4-D; however, diquat is strictly a short-term, burn-down treatment, requiring several treatments in a single season. In addition, both endothall and diquat are relatively nonselective to non-target aquatic plant species. This is in contrast to 2,4-D, which is selective for Eurasian watermilfoil and which can provide control for at least one growing season with a single treatment (Figures 1 and 2).

Herbicides of choice to substitute for 2,4-D for waterhyacinth and ditchbank weed control were diquat and glyphosate. Estimated cost (for materials and labor) for diquat application was approximately $130/A, and with glyphosate, the cost was approximately $150/A.

The obvious reason for these large increases in treatment costs is the greater cost of the alternative herbicide. In no case is the alternative herbicide cheaper than 2,4-D. For Eurasian watermilfoil control, two applications of endothall or diquat would have to be applied in contrast to a single application of 2,4-D. Multiple exposures to these two compounds could be extremely injurious to non-target aquatic plant species. The survey respondents indicated that multiple treatments with alternative herbicides also would be necessary for effective control of waterhyacinth, but that such treatments would be impossible because of current budgetary constraints. If only cost for the herbicide is considered, the weighted average cost for alternative herbicides to 2,4-D for Eurasian watermilfoil control is $245/A in contrast to the current cost of $171/A for granular 2,4-D. The weighted average cost for alternative herbicides to 2,4-D for waterhyacinth control is $74/A in contrast to the current cost of approximately $5/A for liquid 2,4-D formulations. The estimated aggregate cost in aquatic weed control for herbicide alone, if 2,4-D were lost, is about $19.4 million, in contrast to the expenditure of $2.8 million for 2,4-D for aquatic weed control in 1993. This would be almost a six-fold increase in herbicide costs alone, for a net societal loss of $16.6 million annually.

Few agencies indicated that they would switch to non-chemical methods for aquatic weed management. Personnel in one agency indicated an alternative of mechanical harvesting at $1,500/A, and another mentioned the possible use of the grass carp. Mechanical harvesting is slow, labor intensive, and nonselective. Several harvests per season are required to keep up with the growth of the weeds, and this would be difficult on large water acreages. Mechanical harvesting was attempted on Lake Okeechobee in Florida in 1986 with disastrous results (1). The waterhyacinth infestation in the lake increased from 2,000 to 8,000 acres in five months because of the spread of weed parts broken off during mechanical harvest. Grass carp use would be limited because they tend to eat other species of underwater vegetation and leave Eurasian watermilfoil, although they would probably eat it if nothing else were available. Grass carp are not effective for the control of waterhyacinth. In addition, it is not legal to release grass carp in every State. The main non-chemical alternative for ditchbank weed control is mowing, and this can be dangerous to the operator on muddy or steep slopes.

IMPACT OF THE LOSS OF 2,4-D

The respondents were asked to evaluate the impact (from none to severe) of the removal of 2,4-D from the market for eight different water uses (Table 1). The two water uses that respondents felt would be most severely impacted were recreation and navigation. The loss of habitat value was also an area that the respondents believed would be moderately to severely impacted. The reason for this concern is the loss of plant diversity (and concomitant animal life) when invasive weeds are not controlled and allowed to take over. A current example is purple loosestrife, an emergent plant that is invading wetland areas in northern United States. It completely takes over large wetland acreages and has little value for wildfowl habitat and food. None of the current herbicides is very effective for control of purple loosestrife, but there has been some use of 2,4-D on this weed. Infestations of Eurasian watermilfoil and waterhyacinth similarly degrade habitat for fish and many other aquatic organisms. Because 2,4-D is selective for Eurasian watermilfoil, its use does not adversely impact other desirable native plants and may allow them to revegetate some areas. This is seen as a definite advantage for fisheries and waterfowl habitat management. As stated in the survey from the Florida Department of Environmental Protection, "2,4-D is used to selectively remove waterhyacinth from shorelines while maintaining native grasses necessary for fish and wildlife habitat and shoreline stabilization. Loss of 2,4-D would likely mean an increase in diquat and glyphosate use, and a corresponding loss in shoreline grasses."

Other areas that would be severely impacted include public health aspects such as mosquito control, property values and aesthetics, safety at beaches, prevention of flooding in low-lying areas, and water supplies for agriculture.

COMPELLING REASONS TO RETAIN 2,4-D

Respondents were extremely adamant about retaining the use of 2,4-D for aquatic weed management. None of the currently available herbicides are good alternatives. Fluridone is much too expensive for many state and federal agencies or individuals to purchase. Diquat is a burn-down only treatment and thus requires several applications during the growing season to be effective. Furthermore, diquat is not effective in muddy water, which is often present in moving water or large reservoirs. There are few other approved herbicides for aquatic weed control, and they are generally much less effective and all are more expensive than 2,4-D. Although glyphosate is effective on waterhyacinth, it is more expensive to use than 2,4-D. Glyphosate is the only herbicide alternative for ditchbank weed control that is safe for aquatic life. However, not only is it more expensive than 2,4-D, it is nonselective and kills all vegetation. Therefore, it is difficult to maintain a grass cover on ditchbanks if one is forced to use glyphosate.

Several Federal respondents indicated that since budget levels are stationary or decreasing, the loss of 2,4-D would necessitate less acreage being treated. Some mentioned that an increase in the cost of treating waterhyacinth would result in a decrease in the budget to treat other important aquatic weeds such as hydrilla. According to the agency program outline of the Louisiana Revised Statutes, "Without treatment of aquatic weeds (primarily waterhyacinth), many waterways in Louisiana would rapidly be closed to navigation. Maintenance spraying is conducted routinely on many bayous, rivers, lakes and canals. If the entire activity were stopped today, the majority of these now open waterways would close in about six months. It is estimated that the waterhyacinth control program of the Louisiana Department of Wildlife and Fisheries has a direct input in maintaining 3,059,366 acres of wetlands as open water areas, free of waterhyacinth infestation." Another statement prepared by the Louisiana Department of Wildlife and Fisheries indicates that, "If total coverage by aquatic plants of all secondary and other freshwater streams occurred within Louisiana, an estimated 30% of the commercial fisheries catch would be lost annually."

In summary, the respondents indicated that 2,4-D should be retained in aquatic systems because of its excellent record of safety to applicators, the general public, and the environment; its efficacy in controlling some of our most invasive and obnoxious aquatic weed species; and its cost-effectiveness.

IMPACT OF THE LOSS OF ALL PHENOXY HERBICIDES

No phenoxy herbicides other than 2,4-D are currently registered for use in water in the United States.

COMPELLING REASONS TO RETAIN PHENOXY HERBICIDES

Other than 2,4-D, no other phenoxy herbicide is currently registered for use in water in the United States.

WEED RESISTANCE MANAGEMENT

No documented cases of aquatic flowering plant resistance to aquatic herbicides have been reported.

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Table 1. Responses to the questionnaire regarding the impact of loss of 2,4-D on eight water use catagories in the United States during 1992.

	Impact from the loss of 2,4-D				
Use	None	Little	Moderate	Major	Severe
	No. of responses[a]				
Aquaculture	1	6	2	0	1
Drainage	2	2	0	4	3
Hydroelectric	4	3	1	1	1
Irrigation	2	4	1	3	1
Navigation	0	1	3	3	6
Potable water	3	5	1	2	0
Recreation	0	1	3	3	7
Wildlife habitat	0	0	3	5	4

[a] There were 14 respondents to this portion of the questionnaire, but not all respondents rated all water use categories.

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Figure 1. Lake Papakeechie in northeastern Indiana infested with Eurasian watermilfoil in 1985 before treatment with 2,4-D. (Photograph by the author).

Figure 2. Lake Papakeechie in 1986, after treatment with 2,4-D at 28 pounds per water surface area in 1985. Eurasian watermilfoil in this lake is currently managed by mechanical harvesting and spot treatments with 2,4-D or other herbicides. (Photograph by the author).