



Economic consequences of 2,4-D in controlling Canada thistle in irrigated spring wheat  
by Carlton A Infanger

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree  
of Master of Science in Agricultural Economics

Montana State University

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Abstract:

The problem of this research is to develop returns estimates from applying 2,4-D to Canada thistle in spring wheat. In exploring the problem area, an analytic model is constructed in which the returns from a given spray treatment with 2,4-D are expressed as a function of (1) thistle infestation, (2) rate of reduction in thistle count, (3) rate of crop reduction from non-selectivity in the spray, (4) subsequent crop response from reduced thistle count and (5) price received for the crop.

The establishment of relevant assumptions necessitated a development of relationships between the chemical properties of 2,4-D and the physiological and ecological properties of weeds and crops.

In developing the problem, two restraints were used: (1) the quantity of 2,4-D per treatment is fixed at 3/4 pounds per acre; and (2) agronomic practices were taken as given according to practices commonly used in the Gallatin Valley on irrigated crops.

The findings suggest that the operator's decision is sensitively related to the rate of thistle infestation. Within limits set by the problem it appears that he can afford to pay from \$1.22 per acre to \$38.40 per acre as thistles vary from 2.84 to 38.20 shoots per sixteen square feet of area, if spring wheat sells for \$2.00 per bushel. A more productive production environment or a lower price for wheat would lower these maxima in costs; lower productivity or higher prices would raise the maxima. These qualifications stem from the small non-selective properties of 2,4-D and require further evidence for conclusive substantiation.

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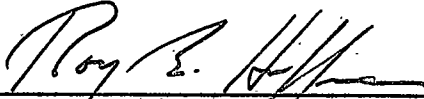
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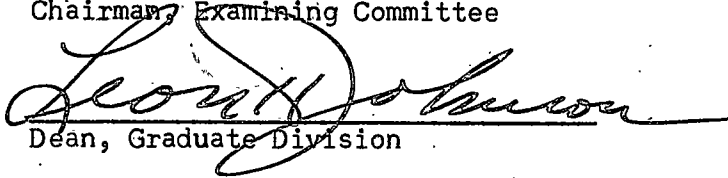
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Any errors of omission or commission are the responsibility of the author.

## ABSTRACT

The problem of this research is to develop returns estimates from applying 2,4-D to Canada thistle in spring wheat. In exploring the problem area, an analytic model is constructed in which the returns from a given spray treatment with 2,4-D are expressed as a function of (1) thistle infestation, (2) rate of reduction in thistle count, (3) rate of crop reduction from non-selectivity in the spray, (4) subsequent crop response from reduced thistle count and (5) price received for the crop. The establishment of relevant assumptions necessitated a development of relationships between the chemical properties of 2,4-D and the physiological and ecological properties of weeds and crops.

In developing the problem, two restraints were used: (1) the quantity of 2,4-D per treatment is fixed at  $3/4$  pounds per acre; and (2) agronomic practices were taken as given according to practices commonly used in the Gallatin Valley on irrigated crops.

The findings suggest that the operator's decision is sensitively related to the rate of thistle infestation. Within limits set by the problem it appears that he can afford to pay from \$1.22 per acre to \$38.40 per acre as thistles vary from 2.84 to 38.20 shoots per sixteen square feet of area, if spring wheat sells for \$2.00 per bushel. A more productive production environment or a lower price for wheat would lower these maxima in costs; lower productivity or higher prices would raise the maxima. These qualifications stem from the small non-selective properties of 2,4-D and require further evidence for conclusive substantiation.

## PART I

### THE PROBLEM

#### A. Introduction and Setting

Weeds have apparently been a problem to mankind throughout most, if not all, of recorded history. It can be noted in some of the earliest Biblical writings of Moses, Genesis 3:18 "... and thistles shall it bring forth to thee ...," that he envisioned them to be a part of the struggle mankind was to face in wresting his living from the earth. From whatever beginning or significance weeds may have had for the primitive farmer, they have become one of the serious economic losses which confront the farmers of this nation, and other nations.

On a national basis, the decrease in crop yields resulting from competition by weeds was valued in a recent (1954) federal government publication (ARS-20-1) at \$2,260,685,000. An additional \$1,486,351,000 was spent to control weeds on agricultural lands, nearly a billion dollars more than was reported for loss to insects.<sup>1/</sup> Although these figures are only estimates, and their accuracy might understandably be questioned, their magnitude would be great enough, even if considerable error of overestimate were present, to show the relative size of the cost involved when compared with the realized gross farm income of \$33,999,000,000

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<sup>1/</sup> Agricultural Outlook Charts for 1956, A.M.S., USDA. Washington D.C., November 19, 1955, p. 11. (Weeds were defined in this estimate as any plant growing where it is not desired: including annual and perennial undesirable herbaceous plants, weedy plants and brush, poisonous herbaceous and woody annuals and perennials, and any other plants encompassed in the definitions of a weed.)

for 1954.<sup>1/</sup> These figures are even more startling when compared with the \$11,814,000,000 realized net farm income for the same year. Figures and comparisons such as these have as their chief benefit the drawing of attention to the overall picture. They leave unasked this important question: What do weeds mean to the individual farm manager or entrepreneur?

Particularly, he needs to know how much of this cost can be eliminated by available practices and finally, how much the practices will increase net farm income. Weeds are somewhat specific to general areas and to particular cropping systems. To be meaningful to the farmer, a specific weed, or group of weeds, should be considered under the conditions which he faces. Weeds and weed control are subject to study, generally speaking, by agronomists. The data from their research as to the competitive effects of a given weed on a particular crop and the effectiveness of various control techniques are part of the information needed by the production economist for economic analysis.

The goal of some groups may be eradication of a particular weed. Economic criteria, however, may lead to something short of complete eradication. It may then be necessary to consider alternate control measures. This is particularly true of weeds which are of such characteristics that their eradication has been subject to control by law.

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<sup>1/</sup> Ibid.

Legal Implications of Weed Control

According to Muenscher, weed control laws on Canada thistle exist in 43 states.<sup>1/</sup> One of these is Montana.

Early Montana Weed Laws

Apparently the mores<sup>2/</sup> of Montana citizens have not coincided with the state's laws in what is acceptable in Canada thistle control. At the beginning of the present century there were only five known areas of Canada thistle infestation: Helena, Bozeman, Craig, Libby and Demersville.<sup>3/</sup> Canada thistle now infests more land in Montana than any other noxious weed.<sup>4/</sup> Yet as early as 1895 Montana law contained specific reference to Canada thistle as a common nuisance and set the land owner liable for its eradication.<sup>5/</sup> "Sections 1197 through 1200 of the 1895 Penal Codes became Sections 8871 through 8874 of the Penal Code of 1907 (RCM 1907). These sections were repealed by Chapter 168 of the Sessions Laws of 1921."<sup>6/</sup>

One finds it difficult to believe that such laws have existed so many years ago and to have the spread of Canada thistle that now exists

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<sup>1/</sup> Walter Conrad Muenscher, Weeds, 2nd Ed., The Macmillan Co., New York, p. 450.

<sup>2/</sup> A sociological term which defines acts or behavior that must be performed to meet the approval of the general society.

<sup>3/</sup> J. W. Blanshenship, Weeds of Montana, Montana Agr. Exp. Sta., Bulletin No. 30, June 1901, p. 35.

<sup>4/</sup> Eugene Heikes, The Weeds, Montana Extension Service, Number II, March 1956, p. 6.

<sup>5/</sup> Penal Code of Montana, Approved March 18, 1895, Sections 1197 through 1200.

<sup>6/</sup> Letter from Arnold H. Olsen, Attorney General of Montana, 10/18/55.

in Montana. In the same letter as referred to previously and in answer to the question: "What legal action has ever been taken in Montana on cases of failure to control noxious weeds?" This answer was given: "I don't find too much legal writing on the subject." In addition the references that were cited did not cover a Montana case. It seems likely then that no one has been prosecuted for failure to comply.

#### Present Montana Weed Laws

"Weed control at present is dealt with in Sections 11-985 of the Revised Codes of Montana, 1947, and Sections 16-1701 through 16-1722 of the same code as amended in 1951."<sup>1/</sup> Part (a) of Section 1701 defines Canadian thistle to be a noxious weed and a common nuisance. Part (c) defines the area included within the boundaries of any organized weed control and weed seed extermination effort to be a "district." Section 1702 of the same codes states "it shall be unlawful to permit any noxious weed, as named in this act, or designated by the Board of County Commissioners of the respective county, to go to seed on any lands within the area of any 'district'."<sup>2/</sup> Figure 1 shows the areas or counties in the State of Montana where such districts are in effect as of January 1956. In such districts it seems advisable to know what action is required by law before a control or eradication program is considered to be satisfactory by any other criteria.

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<sup>1/</sup> Ibid.

<sup>2/</sup> Revised Codes of Montana 1947.

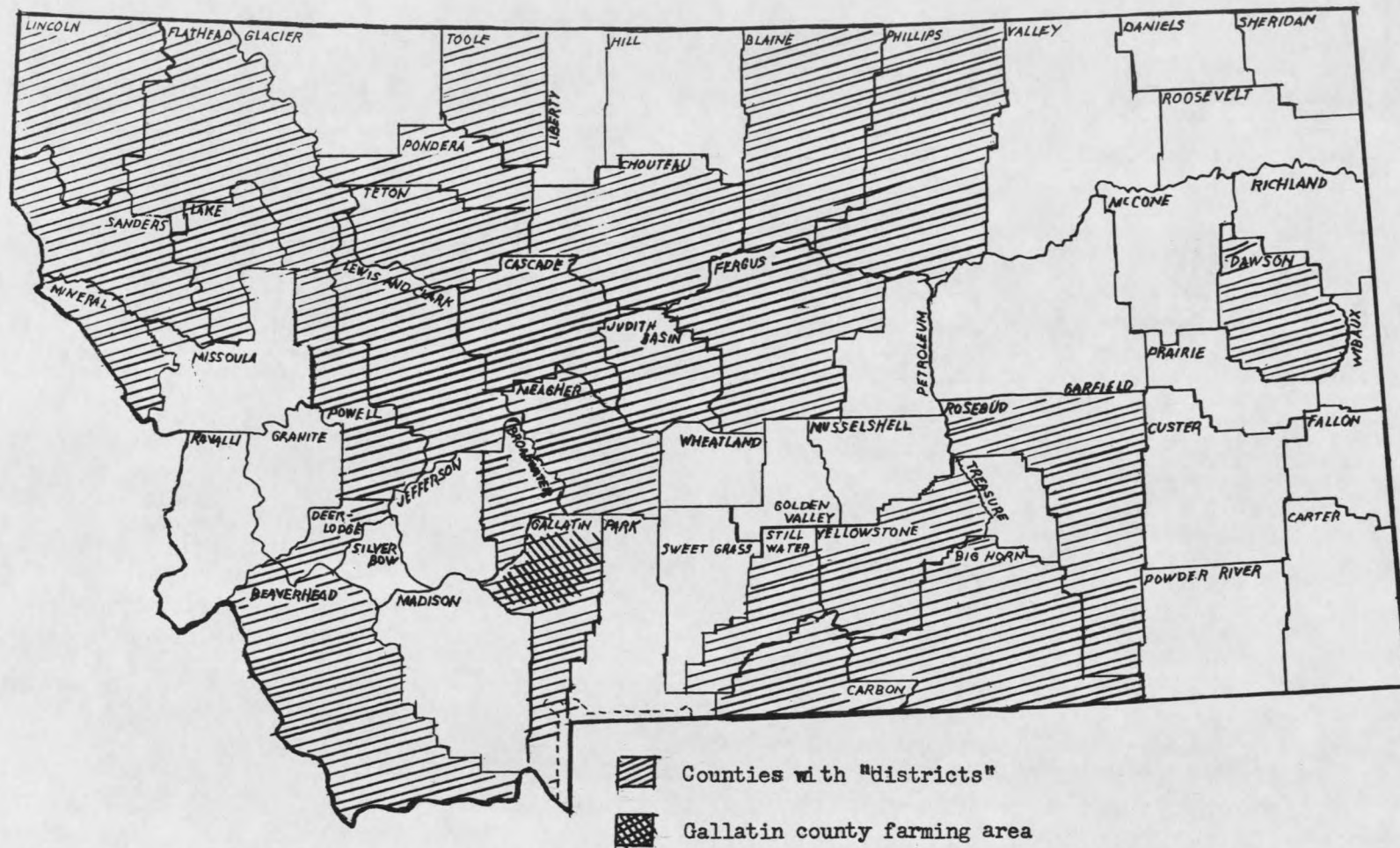


Figure 1. Counties of Montana with weed control districts in effect January 1956.

Review of Literature

The Weed

Several botanical descriptions, of similar context, for Canada thistle (Cirsium arvense (S.) Scop.) are available in various publications. But without an understanding of the technical terms used they mean little to the reader. Canada thistle, however, does have some readily recognizable and describable characteristics which aid in distinguishing it from other thistles. It is customarily distinguished from other thistles by its deep green, irregularly margined and intensely spiny leaves, by small heads of purple flowers borne in clusters. The plants grow in patches, with horizontal branching roots.<sup>1/</sup> The leaves of Canada thistle vary greatly in the amount of hairiness, degree of lobing and spininess which give rise to descriptions of four varieties: integrifolium, vestitum, mite, horridum. Although all four of these so-called varieties may be present, they represent only such leaf structures as can be found in various patches of thistle.<sup>2/</sup> These variations require more than casual knowledge to be distinguished. If there is a difference in the ability of these varieties to resist eradication, it would be important to distinguish them. Canada thistle is the only thistle with male (staminate) and female (pistillate) flowers on separate (dioecious) plants. The flower heads vary from rose-purple to pink to (less frequently) white. Globular in the male plants, and more or less flask-shaped (egg or ovoid)

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<sup>1/</sup> C. H. Ahlgren, G. C. Klingman, and D. E. Wolf, Principles of Weed Control, John Wiley and Sons, Inc., New York, 1951, p. 290.

<sup>2/</sup> Walter Conrad Muenscher, Weeds, 1st Ed., The Macmillan Co., New York p. 476.

in the female, they are small and numerous compared with those of other thistles.<sup>1/</sup> The feathery, fluffy heads of the female are easily distinguished when the seeds are mature.

#### Propagation of Canada Thistle

Canada thistle reproduces by two means: from its creeping root system, nearly every piece of which can give rise to a new plant, and from numerous seeds which are easily scattered by the wind and which have a great longevity.<sup>2/</sup> Propagation from seed requires that male and female plants grow in close enough proximity that pollination can take place. Male plants produce pollen. Female plants, although they produce seeds, must be pollinated if the seeds are to be fertile. Where only one type of plant is present no seed is produced and this may partially account for the belief, in some localities, that it does not seed. When viable seeds are produced they give rise to a widespread social problem of control. In the author's opinion, after observation throughout the Gallatin Valley, such a problem may rapidly be approaching in this area.

Another reason why Canada thistle appears not to reproduce seed is that it is subject to attacks by certain insects such as Dasyneura Gibsoni, Canada thistle midge, and Trypeta Florescentioe, whose larvae feed on and destroy the undeveloped achenes (fruit seed). Severe attacks by these and other insects may entirely prevent Canada thistle plants from maturing seeds.<sup>3/</sup>

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<sup>1/</sup> Clarence Franklin, Weeds of Canada, Queen's Printer, Ottawa 1955, p. 164.

<sup>2/</sup> Muenscher, 1st Ed., op. cit.

<sup>3/</sup> Ibid.

The wind blown seeding of Canada thistle is spectacular. But its ability to reproduce perennially and vegetatively from rhizomes cause more concern to those attempting its control or eradication. Frequently rhizomes are sometimes called rootstocks. But, since they have such stem characteristics as nodes, internodes, and scale leaves at the nodes, the term "rhizomes," meaning "underground stems," is more descriptive and accurate. These rhizomes are more or less cylindrical stems growing horizontally underground. They may be slender or fleshy. In either event, they are generally capable of a rich store of food for the next season's early growth. Any piece of these rhizomes that has at least one node, with a bud in the axil of each scale leaf at the node, is capable of producing a new plant.<sup>1/</sup> It is not necessary for rhizomes to be broken to cause them to reproduce. At the end of each growing season, the above ground growth dies back. Even without disturbance, new aerial shoots will grow from the buds the following season. It seems to follow then, that in order to control or eradicate Canada thistle, the measures taken must be able to kill the buds of the rhizomes as well as the top growth if propagation is to be prevented.

#### Physiology of Canada Thistle

In general the functions of plant stems are support and conduction. For control purposes, studies of conduction are of the greater importance. In perennial plants, as previously described, it is necessary that, by

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<sup>1/</sup> For a more complete discussion of rhizomes and vegetative reproduction, a competent book of botany such as Botany by W. W. Robbins and T. E. Weier, John Wiley and Sons, New York, 1952, should be consulted.

some process, the excess food that is manufactured in the leaves or other parts be conducted to a storage area. Once food reserves are stored, if they are to be of further use to the plant, there must be a system of transporting them to the point of new growth until it is capable of making its own food.<sup>1/</sup>

The movement of food reserves in Canada thistle and the quantities available for growth are determined to a large degree by the stage of growth or dormancy. Apparently the root reserve curve shows a drop for about a month after spring emergence, followed by a general rise over the period until seeds begin to ripen, after which a gradual fall occurs until emergence the following spring when a sharp drop again occurs.<sup>2/</sup> A point of low root reserves causes a general weakening of the plant at about the pre-bud stage of growth. Therefore, this seems the time at which it could be most effectively attacked by control measures. It is recommended that a cultivation program for the control of Canada thistle in Montana begin about mid-June to coincide with this period of low supply of readily available and total carbohydrates.<sup>3/</sup>

#### Ecology

Competition among plants begins when there is less space, light, water, minerals, or salts in the soil than is required for all plants concerned. Any one of five may be insufficient for the demand or a

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<sup>1/</sup> Ibid.

<sup>2/</sup> W. W. Robbins, A. S. Crafts, R. N. Raynor, Weed Control, McGraw-Hill Book Co., Inc., New York, 1952, pp. 433-34. Initial work at the Montana Experiment Station seems to generally support this type of curve.

<sup>3/</sup> Montana Agricultural Experiment Station Bulletin 426, p. 7.

combination of any or all of them. Weeds have been called "the robber barons of agriculture."<sup>1/</sup> They compete with crops for light, water, minerals, salts, and space needed for growth. It might be suspected that if weeds do not compete for these items, rates and methods of planting of crops could be improved.

Either the crop or the weed can dominate in competition. If the crop can emerge before the weeds and grow more vigorously than they, it will tend to suppress them. If the reverse is true, the crop will suffer. Pavlychenko, Kirk and Kossar point out that if land is seeded early and thickly to barley, by the time the shoots of Canada thistle emerge, the field is so well occupied by the crop that the thistle will suffer from shading.<sup>2/</sup> In other studies, it is suggested that when plants grow very closely, the overlapping of root systems is a source of competition before the tops begin to shade one another.<sup>3/</sup>

Another Canadian worker, E. G. Anderson,<sup>4/</sup> reported that: "Investigation has indicated that the number of tillers, branches or stems that wheat, oats, or barley will support is determined in the early one-leaf stage. For some reason any root interference, even 10 weeds per square

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<sup>1/</sup> Robbins and Weier, Botany, op. cit. p. 270.

<sup>2/</sup> T. K. Pavlychenko, Professor of Plant Ecology, L. E. Kirk, Dean of Agriculture, W. Kossar, Research Assistant at the University of Saskatchewan, Eradication of Perennial Weeds by the Shallow Cultivation Method. Univ. of Saskatchewan, Agricultural Extension, Bulletin 100, p. 6.

<sup>3/</sup> Robbins and Weier, Botany, op. cit., p. 59.

<sup>4/</sup> Associate Botanist and Secretary, National Weed Committee, Botany and Plant Pathology Laboratory, Science Service, Canada Department of Agriculture, Ottawa, Ontario.

yard, influences tillering. These interferring weeds cannot be killed by spraying as the grain plants are too sensitive. One must wait until about the four-leaf stage for the grain to have sufficient resistance, but, by then the damage by competing weeds has been done.

"The number of kernels the head will bear is determined by the time the grain plants are in the two-leaf stage. Just as herbicides are most usefully employed in pastures when combined with fertilizer and good management so should tillage implements be combined with herbicides for the control of weeds in cereals. Implements such as rod weeders or harrows used before and after germination, would kill a large percentage of annual weeds at a stage when they cannot be sprayed and when they determine, to a large extent, the reduction which will take place in the crop."<sup>1/</sup> Some losses from weed competition are apparently unrecoverable if control measures are used too late to prevent the damage.

Some work has been done to determine to what extent crop yields are reduced by competition from certain weeds. Anderson reported yield loss in cereals to be related to degree of wild mustard infestation (see Table 1). Others found that wheat containing 7 sow thistles per square foot experienced a loss of 71.06 percent compared to wheat free of sow thistle competition.<sup>2/</sup> Studies of this type have been made at the Montana Agricultural Experiment Station as a part of this experiment for Canada thistles and will be included in the section on empirical evidence.

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<sup>1/</sup> E. G. Anderson, The Economic Value of Herbicides to Canadian Agriculture, a report to the first meeting of Agricultural and Pesticide Technical Society, McDonald College, Quebec, June 21-24, 1954.

<sup>2/</sup> Robbins, Crafts, and Raynor, op. cit., p. 59.

### Chemical Weed Control

Chemicals in such common forms as salt, ashes and industrial wastes have been used for hundreds of years. It is not known when they first came into use. Their use was most likely as a soil sterilant, either long or short term depending upon the area involved. In the latter part of the eighteenth century, it was noted that the spraying of chemicals to control plant diseases in cereals caused the death of broad-leaved weeds. In a short period of 14 years (1896-1910) a number of workers in both Europe and America found various solutions which would selectively control weeds with little damage to crops.<sup>1/</sup>

TABLE I. EFFECT OF WILD MUSTARD COMPETITION ON YIELD OF CEREALS.<sup>a</sup>

Crop	Percentage of Reduction in Yield When Wild Mustard Constitutes:			
	1-20%	21-40%	41-60%	
Wheat	Avg. for 9 yrs.	15	35	53
Oats	Avg. for 9 yrs.	14	46	63
Barley	Avg. for 9 yrs.	11	49	69

<sup>a</sup>Source: Anderson, op. cit., p. 2.

While chemical weed control continued to gain in popularity in Europe, it was losing interest, where annual weed control was concerned, in America, where types and intensity of farming and climatic

<sup>1/</sup>Robbins, Crafts and Raynor, op. cit., p. 123. More details are offered throughout Chapter 8 of this publication.

conditions were different.<sup>1/</sup> More attention has been turned to perennial weeds in America. In the past 40 years, particularly the last 15 years, chemical weed control has become "big business."

2,4-D did not come into wide usage until 1945. The literature prior to 1945 contains practically no information on 2,4-D and related compounds. National security regulations during World War II delayed the dissemination of information of 2,4-D by nearly 5 years. Since that time its advent has caused an almost unending series of articles in various periodicals and book revisions as more and more information has become available on its usage. By 1949 approximately 20,000,000 lbs.<sup>2/</sup> of 2,4-D were manufactured in the United States. If an equal amount were sprayed at an average of 1 lb. per acre for the same year, it is easy to estimate the amount of acres covered. It is estimated that 31,101,000 acres were sprayed for brush and weeds in 1952.<sup>3/</sup> Figures are not immediately available for the current year (1956). However, 2,4-D has become almost synonymous with weed control in some circles.

#### The Chemistry of 2,4-D

It has been known for a number of years that plants produce hormones for the control of their growth. One such hormone is indole acetic acid which can be isolated from plants and synthesized in a chemistry laboratory. The structural formulas for this acid and 2,4-D have some common

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<sup>1/</sup> Ibid., p. 44.

<sup>2/</sup> Ibid., p. 125.

<sup>3/</sup> A. P. Brodell, P. E. Strickley, H. C. Phillips, "Extent and Cost of Spraying and Dusting on Farms," 1952, Statistical Bulletin No. 156 USDA, ARS April 1955.

features. In Figure 2 the theorized chemical arrangement of a molecule of 2,4-D is shown. It has in common with the indole acetic acid the

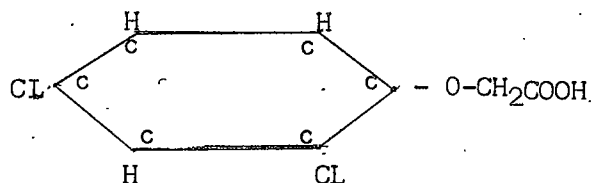


Figure 2. Theoretical model of 2,4-D molecule

benzene ring and  $\text{CH}_2\text{COOH}$  group attached to it. They differ in the method of attachment of the radical: 2,4-D through the oxygen and indole acetic acid through the indole ring. This molecule represents the parent acid which is a white powder, nearly insoluble in water and only slightly soluble in oil. Two of the hydrogen atoms have been replaced by chlorine atoms at the number 2 and 4 positions following the oxygen. This arrangement of atoms gives rise to the name 2,4-Dichlorophenoxyacetic acid, the phenoxy denotes the oxygen.<sup>1/</sup> (Hence the common name 2,4-D.)

Since this parent acid of 2,4-D is insoluble in water, it is necessary that it undergo further reactions to produce substances that will be soluble or emulsifiable in oil or water for practical use as a spray. One of the two more common reactions which are used is the addition of a base to the acid to form a salt. The use of sodium-bicarbonate will yield sodium salt which is soluble in water. The amine salt is formed by combining one of the ethanal, mono-, di-, or tri-, amines to the acid. The second reaction generally involves the combining of an organic base such

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<sup>1/</sup> For a more complete discussion the I.U.C. system of naming organic compounds should be consulted.

as methyl, ethyl, or isopropyl alcohol with the acid to form an ester of 2,4-D which is insoluble in water but soluble in oil or alcohol. If these ester compounds are to be used in water they must first be dissolved in mineral oil containing an emulsifying soap.

In either ester or amine compounds, effectiveness of 2,4-D depends on characteristics derived from the parent acid molecule. The different formulations are made only to render the acid soluble in the carrier, usually water or light oil, to be used. The different methods of rendering it soluble may give different acid equivalents for any given amount of solution. Recommendations for using 2,4-D are, therefore, made in terms of pounds of the parent acid. Results from the use of 2,4-D under field conditions will also depend upon the ease with which plants can absorb the different formulations. This in turn depends partly on the stage and rate of their growth, the carrier in which the formulation is emulsified or dissolved, and the temperature at and prior to the time of spraying.

#### Physiological Effects and Selectivity of 2,4-D

Hormones are defined as organic products produced in one part of a living organism and transported through the fluids of the organism to produce a specific effect on the cells in another area to which it is transported. Like hormones, 2,4-D can be absorbed by the leaves and moved in the carbohydrate conductors to regions where food is being stored.

It was first supposed that 2,4-D gave toxic results by causing the plants to grow themselves to death. This view was perhaps stimulated by

the knowledge that growth and yields could be improved by minute quantities. Hodgson<sup>1/</sup> reported, however: "In experiments by Mitchell and Brown it was shown that treated plants do not grow, they cease growing. They concluded that plants die because their food reserves are depleted or burned up." Hodgson further reported that investigators generally agree that the death of plants is due to inhibition of translocation and formation of food reserves.

Robbins, Crafts and Raynor, reporting on the work of Van Overbeek, wrote: "Based on the facts that 2,4-D will stimulate respiration, starch hydrolysis, and depletion of food reserves, Van Overbeek (1947) has proposed that, 2,4-D, like natural auxin, might affect oxidative assimilation in the cell by catalyzing transphosphorylation with an attendant energy release. Unlike auxins, 2,4-D might escape inactivation by oxidases present in the plant that normally regulate metabolism. Thus, if the catabolic processes in the cells were greatly increased while the anabolic system was blocked, the plant would suffer rapid injury. Many symptoms of 2,4-D injury indicate that some such process is responsible."<sup>2/</sup>

As toxic as 2,4-D is, its chief value derives from the ability of various plants to resist this toxicity. In general, broad-leafed plants are susceptible, and grasses are resistant. This is the common basis for its use as a selective spray. The most important factors which determine selectivity are associated with the plant and are as follows:

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<sup>1/</sup> Jesse M. Hodgson, Growth Regulating Substances for the Control of Weeds in Kentucky Bluegrass Lawns, Masters thesis on file in the library of Montana State College, p. 16.

<sup>2/</sup> Robbins, Crafts and Raynor, op. cit. p. 151.

"(1) physiological differences; (2) differential absorption; (3) differential wetting; (4) differential translocation; and (5) morphological differences."<sup>1/</sup> These various factors are discussed in some detail in the work cited.

In addition to plant factors, the ester formulations of 2,4-D seem to be more readily absorbed than do the amine formulations.

While it is important to know which are susceptible or resistant to 2,4-D, it is well to keep in mind that any given plant may, at different stages of growth, exhibit different degrees of resistance. It is true that grasses in general are resistant at some stages of growth. However, they can suffer greatly as seedlings from an application of this herbicide. Small grains seem susceptible to 2,4-D in the seedling stage (one or two leaf), and just prior to and during blooming (pollination period).<sup>2/</sup> Much work has been done in an effort to determine just when these susceptible periods do occur. This is important in devising means which avoid them, if possible, when using 2,4-D sprays.

Much of this work has been summarized in graphic form. Some results relating to wheat are shown in Figure 3.<sup>3/</sup>

It appears that with only  $\frac{1}{2}$  pound rate of application at the jointing stage, yields were not reduced. In fact, a slight increase is shown. All

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<sup>1/</sup> Ahlgren, Klingman, and Wolf, op. cit., p. 81

<sup>2/</sup> Ibid., p. 130.

<sup>3/</sup> Complete details of these experiments will not be attempted in this review but adequate source references will be given for those who require them.

stages show decreases at  $\frac{1}{2}$  pound and higher rates. The author concluded that the increase at  $\frac{1}{2}$  pound rate was not significant nor were decreases serious up to  $\frac{1}{2}$  pound rate.<sup>1/</sup>

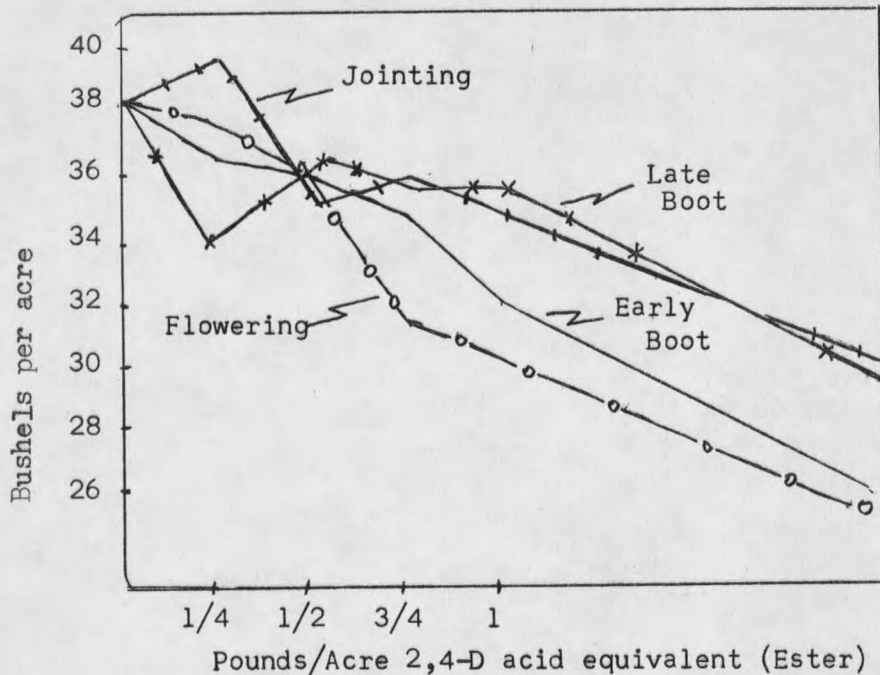


Figure 3. Three year average of yields, in bushels per acre, of Pawnee wheat as affected by 2,4-D applications at four stages of growth.

Source: D. S. Klingman, "Effects of Varying Rates of 2,4-D and 2,4,5-T at Different Stages of Growth on Winter Wheat," Agronomy Journal, Volume 45, Number 12, p. 607. This work was done at the Neb. Agr. Exp. Sta. during 1948 to 1950.

Woofter and Lamb summarized the average effects of two ester formulations applied at the rate of one and three pounds acid per acre as shown in Figure 4. In other winter wheat studies similar results were obtained.<sup>2/</sup>

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<sup>1/</sup> Klingman, op. cit.

<sup>2/</sup> W. C. Shaw, C. J. Willard, R. F. Bernard, The Effect of 2,4-D on Wheat, Oats, Barley, Research Bulletin 761, Ohio Agr. Exp. Sta.

The results from experiments in spring wheat resistance has shown somewhat similar stages of susceptibility. Figure 5 gives a summary of results at Morden and Brandon, Manitoba, Canada. The authors conclude in a summary that there are two critical periods in wheat at which yields are reduced sharply.<sup>1/</sup> The first occurs at the seedling stage and the second, from 11 to 12 days before heading to nearly fully headed.

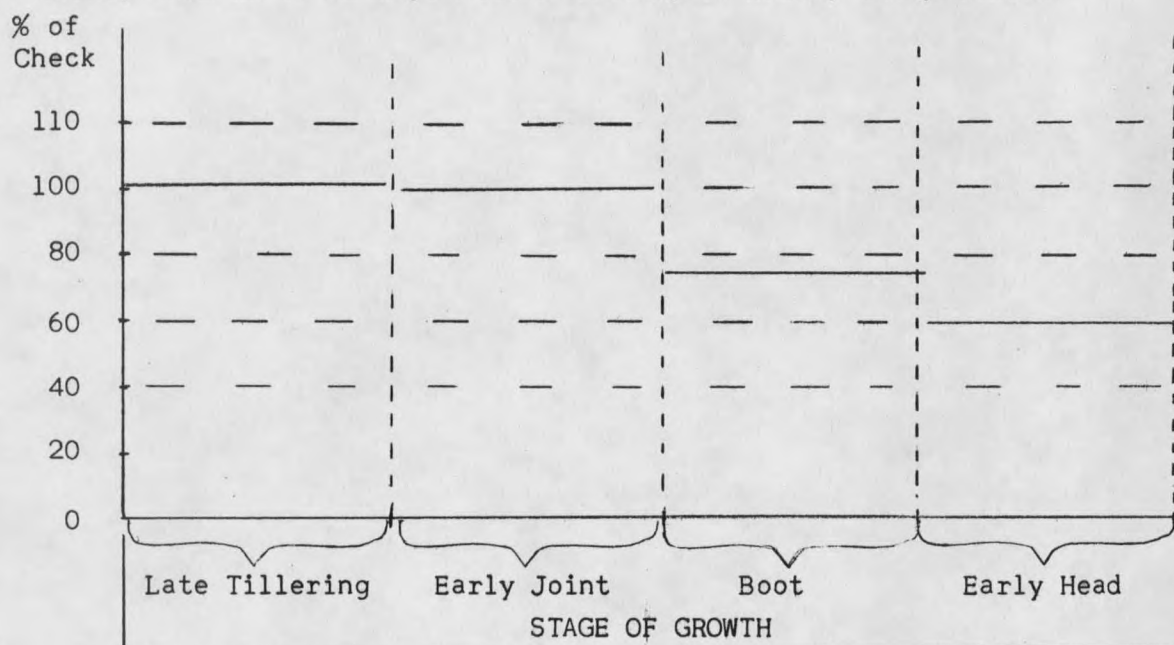


Figure 4. Yield of Thorne wheat shown as percentage of controls following treatment with 2,4-D formulations.

Source: H. D. Woofter, C. A. Lamb, "The Retention and Effect of 2,4-Dichlorophenoxyacetic Acid (2,4-D) Sprays on Winter Wheat." Agronomy Journal Volume 46, Number 7, pp. 300-301.

Trials on the resistance of wheat to 2,4-D applications at various growth stages have been carried out by the Department of Agronomy and

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<sup>1/</sup> P. J. Olson, Saul Zalik, W. J. Breakey, and D. A. Brown, "Sensitivity of Wheat and Barley at Different Stages of Growth to Treatment with 2,4-D," Agronomy Journal, Volume 43, Number 2, p. 82.

Soils at Montana State College. In an unpublished report of progress for the calendar year of 1951, it was concluded that, "yields were affected most by applications at stages prior to tiller formation and at one date five days after heading."<sup>1/</sup> Also included in this report is a summarization of four years' results from four rates of 2,4-D application on three different varieties of wheat at two dates. The dates and stages of growth

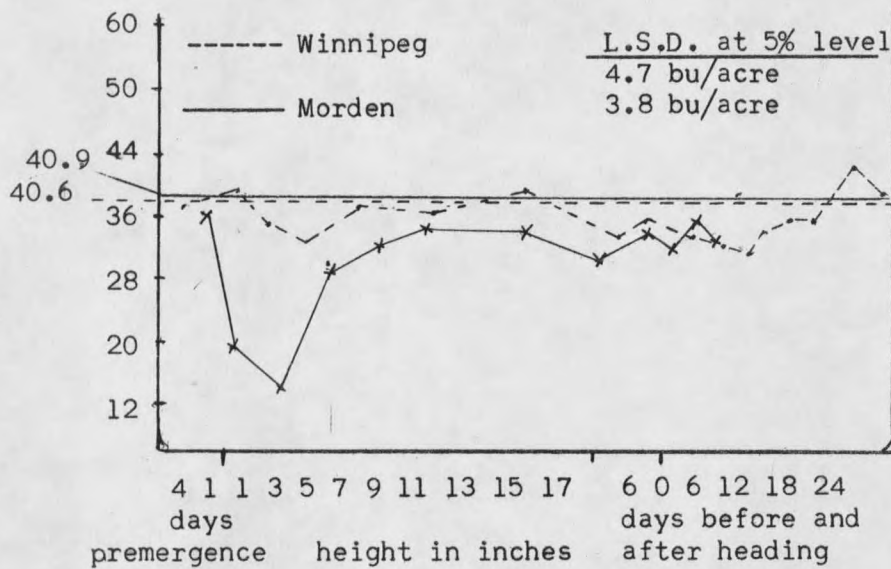


Figure 5. Yield of Redman wheat under treatment with the butyl ester form of 2,4-D applied at various stages of growth at 8 and 12 ounces pure acid per acre for Morden and Winnipeg respectively.

Source: P. J. Olson, Saul Zalik, W. J. Breakey, and D. A. Brown, "Sensitivity of Wheat and Barley at Different Stages of Growth to Treatment with 2,4-D," Agronomy Journal, Volume 43, Number 2, p. 82.

varied somewhat for different years but were generally early and late tillering stages. The indications from these data are: "That under

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<sup>1/</sup> Explanation of Table VII in the unpublished Report of Progress for the Department of Agronomy and Soils of Montana State College, June 30, 1952, p. 7.

weed-free conditions such as existed in these trials the spring wheat varieties tested can tolerate rates of 2,4-D as high as 1 pound without serious yield reductions. These data further indicate an increasing yield reduction due to rates.<sup>1/</sup> The summary of these data is shown in

Table II.

Some reductions in yield may be attributed to rates and dates of application. Other factors, such as temperature at time of spraying and volume and type carrier used, need also to be considered.<sup>2/</sup>

With the information in this section as a general description of the area of chemical (2,4-D) weed control, a theoretical economic approach can be developed that will point out the factors which will lead to the economic solution of a particular weed (Canada thistle) control problem.

#### B. Selection and Formulation of Research Problem

##### Theoretical Approaches to Optima in Resource Use

The objective to be achieved, as stated in the original project statement, is to determine the effect on net value of product of alternative techniques for controlling Canada thistle in small grain. Some alternatives that might be considered in the control of Canada thistle include such measures as mowing, competitive cropping, cultivations, rotations, spraying 2,4-D emulsion or solution, and combinations of the foregoing.

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<sup>1/</sup> Ibid.

<sup>2/</sup> R. L. Warden, The Effects of Rates of 2,4-D Volumes and Types of Carrier and Stages of Growth in Sterility Injury in Spring Wheat. Masters thesis on file in library of Montana State College, p. 52.

TABLE II. SUMMARIZATION OF MEAN YIELDS FOR THE THREE SPRING WHEAT VARIETIES TREATED WITH THE LISTED RATES AT TWO DATES PER YEAR OVER A FOUR-YEAR PERIOD, ON WEED-FREE PLOTS.

Variety	Rate	1948	1949	1950	1951	Mean	% of Check
Thatcher	0	32.0	46.6	42.6	48.1	42.3	---
	.25/.33	28.1	51.1	42.3	45.4	41.7	98.6
	.50	---	---	33.4	50.0	41.7	91.6
	.67	28.0	44.9	---	---	36.5	92.9
	1.00	24.8	47.9	36.7	44.1	38.8	91.7
Ceres	0	31.0	50.0	46.5	54.3	45.5	---
	.25/.33	27.2	48.4	41.9	52.0	42.4	93.2
	.50	---	---	42.5	47.1	44.8	88.9
	.67	28.1	47.3	---	---	37.7	93.1
	1.00	27.4	49.4	37.7	46.0	40.1	88.1
Rescue	0	32.3	49.5	44.0	50.9	44.2	---
	.25/.33	33.4	44.7	41.6	48.7	42.1	95.2
	.50	---	---	43.5	48.0	45.8	96.4
	.67	29.6	44.6	---	---	37.1	90.7
	1.00	31.4	43.5	35.5	51.1	40.4	91.4
All varieties	0	31.8	48.7	44.4	51.1	44.0	---
	.25/.33	29.6	48.1	41.9	48.7	42.1	95.7
	.50	---	---	39.8	48.4	44.1	92.3
	.67	28.6	45.6	---	---	37.1	92.1
	.75*	---	---	---	---	---	91.7*
	1.00	27.9	47.5	36.6	47.1	39.8	90.5

\*Linear interpolation added by this author.

Source: Unpublished Report of Progress for the Department of Agronomy and Soils of Montana State College, June 30, 1952, p. 9.

In light of the tremendous increase in the use of 2,4-D since 1944, it seems justifiable to attempt the establishment of a methodological economic approach to its use in a specific weed problem in small grains. It is hoped that the methodology used will be sufficiently flexible to allow its adaptation to similar production problems in weed, insect, or disease control in particular circumstances.

In the solution of an economic problem it is necessary to know or assume what the goals of the operator are. We shall assume for this study that the farm operator's goal is to maximize the contribution of the enterprise to net farm income. This assumption will facilitate the solution to problems in production alternatives, around which decisions center, by allowing the use of measurable quantities. While the production alternatives have been variously classified,<sup>1/</sup> the problem we will want to solve is one of determining whether a production "practice" should or should not be used from a profitability standpoint.

"We shall mean by 'practice' an alternative which is selected in total or not at all -- e.g. selection of variety A instead of variety B. A decision of a wheat farmer to comply or not comply involves choice of a 'practice'."<sup>2/</sup> The distinction between the production alternative of "practices" and resource combination is difficult, and for many purposes, not worth the effort.<sup>3/</sup> It may well be that a differentiation is not called for as the "practice" could be in the resource combinations. What then is the distinction?

The "practice" we recall is defined to be an all or none (either/or) type of use. Resource services or inputs in resource combinations are

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<sup>1/</sup> Earl O. Heady, Economics of Agricultural Production and Resource Use, Prentice-Hall, Inc., New York, 1952, p. 26.

<sup>2/</sup> C. B. Baker, "Criteria for Problem-solving in Farm Management," paper given at Western Regional Farm Management Research Conference, Fort Collins, Colorado, June 16, 1955.

<sup>3/</sup> Ibid.

commonly thought to be divisible and usable in quantities from infinitely small to infinitely large. More frequently in use, at least, they are in readily measurable quantities of the item involved. The relationship between some completely divisible variable input and the amount of product produced is the more common type of graphic illustration found in economic literature. In many instances it is drawn to represent such a relationship between input and output that at various levels of input increasing, decreasing, and diminishing returns to the factor are apparent.<sup>1/</sup>

Somewhat less frequently, illustrations are found of inputs that can be divided into discrete units. Graphically, the relationship between discrete units of an input and the product produced by its use is shown in Figure 4. A continuous function is not the case for such a relationship for the amount of product can be determined only for the number of finite units that the resource is divided into. If we draw lines connecting these points, as the dotted lines in Figure 6 a, they are at best a working hypothesis as to what might occur if the input were divisible. The existence of these lines are more for usefulness in the analysis of such discontinuous functions than for any attempt at giving them a real meaning.

Associated with a discontinuous production function are the marginal (MPP) and average (APP) product functions of Figure 6 b. MPP and APP are identical in such cases. By assuming linear relations between points

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<sup>1/</sup> Heady, op. cit., p. 43.

on the production function, our analysis is simplified since we no longer have an infinite number of alternatives to choose between as with continuous curvilinear functions. The various types of returns are shown in this discontinuous consideration. A unit of increase in the resource either adds to the amount of total physical productivity (TPP), leaves it unchanged, or decreases it so that diminishing returns are still demonstrated. It is unlikely, here, that an entrepreneur would use an amount ( $x_{25}$ ) of  $x_2$  which would decrease the  $TPPx_2$ . If the segments of the curve are thought of as parts of a curve consisting of linear segments, our attention is turned to returns of a constant rate between points. A more realistic presentation of the productivity of discrete units of a variable factor might be made in the form of bar charts.<sup>1/</sup>

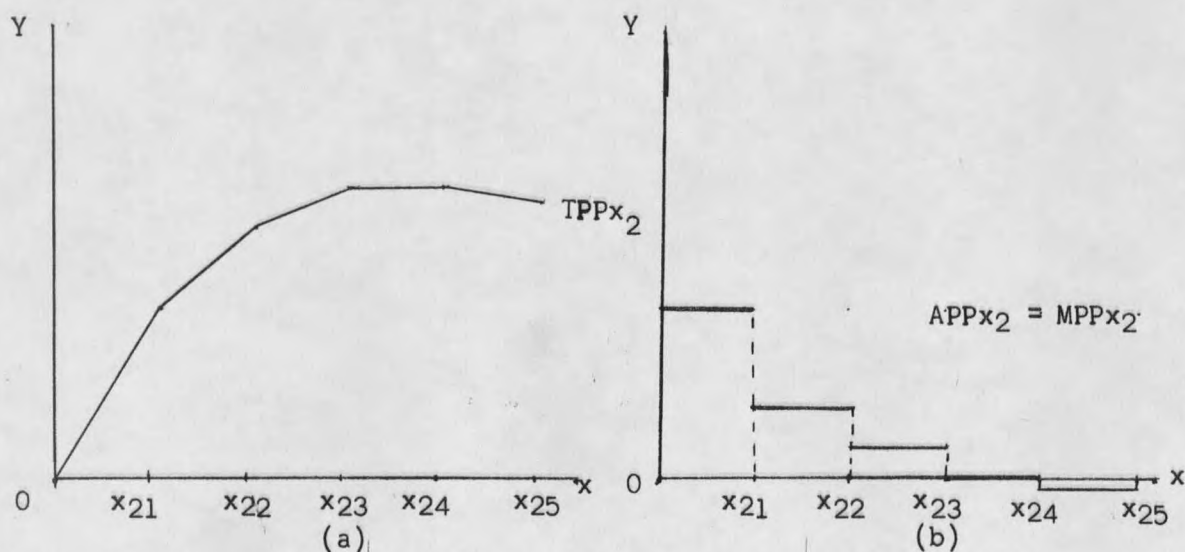


Figure 6. The productivity of a variable resource service that is divisible into discrete units; (a) the total productivity and (b) marginal and average productivity.

<sup>1/</sup> Ibid., p. 51.

Another possibility in the use of a resource service or factor is that it can be used as a fixed given unit or not used at all. The operator will want to know if the product which is produced, from the use of such a factor has a value equal to or greater than the cost of the input. It may be tempting to illustrate the productivity of such a resource service as in Figure 7. From whatever production was ( $Y_0$ ) without the input it would rise to a new level  $E$ . Unless we use care in interpreting this graph, we might be led to believe that the input ( $x$ ) could be used at some rate other than ( $x_1$ ) which gives a linear relationship between zero and ( $x_1$ ) of ( $x$ ).

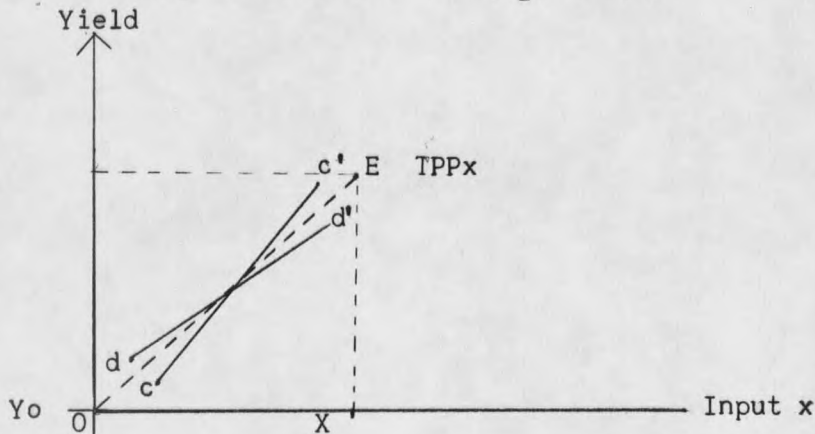


Figure 7. Total physical product of a practice with price ratios imposed to illustrate profitability.

Although linear relationships do occur in some production considerations, it can be assumed for an analysis that the  $TPPx_1$  curve exists only at the point  $E$  and is only imaginary throughout the remainder of its length. To determine if it will be profitable to use the factor at the single amount  $x_1$  we will, if linearity is assumed, need to know

the ratio  $Px_1/P_Y$  which determines the character and slope of a line depicting the ratio. There are an infinite number of slopes which this ratio can depict but to determine the solution for the use or non-use of  $x_1$  it is only necessary to know whether this slope is ( $>$ ) greater than or ( $<$ ) less than the slope of the line from the origin to E. If the slope of  $Px_1/P_Y$  ratio line is  $>$  as is  $cc'$ , we would not use  $x_1$ . When  $dd'$  represents the slope of the  $Px_1/P_Y$  ratio line the use of  $x_1$  would be profitable. Under linear conditions then, the amount of product produced will either be the amount without any of the factor or the maximum that can be produced with the use of the factor. Since this line (OE) representing linearity does not exist in reality, it may be well to give an illustration which is more realistic.

In the discussion of discontinuous functions for discrete units of input mention was made of bar charts. If the difference between the amount of product produced without the use of a "practice" and the amount with the use of a "practice" are shown in a bar chart, it would probably appear as in Figure 8, page 29.<sup>1/</sup>

#### "Break-even" Solutions in the Use of a "Practice"

Without considering opportunity cost, to determine the profitability of the use of the "practice" (A)<sup>2/</sup> it is necessary to consider the increment in yield that is forthcoming with its use. A solution for the profitability of the "practice" can be determined algebraically if the product

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<sup>1/</sup> The "practice" would probably not be considered if the amount of product forthcoming were less than without its use.

<sup>2/</sup> The first letters of the alphabet are generally used to indicate a constant.

price and the cost of the factor are known. If the increment in yield ( $\Delta Y$ ) times its price ( $P_Y$ ) is greater than or equal to ( $\geq$ ) the "practice" (A) times its cost ( $P_A$ ), use of the "practice" (A) will be profitable. The quantity (A) is used to represent a fixed amount of resource services being used. In equation form it would be:  $(A) (P_A) \leq$  (less than or equal to)  $(\Delta Y) (P_Y)$ . By simple algebraic manipulation this equation can take on a variety of forms to fit the needs of the situation. For example if we wish to know ( $P_Y$ ) when the other parts are known the above equation can be written  $P_Y = \frac{(A) (P_A)}{\Delta Y}$ . The ( $P_Y$ ) thus found is a minimum for profitability. Or we may wish to know how much (A) can cost ( $P_A$ ) given ( $\Delta Y$ ), ( $P_Y$ ), and (A). In this case our equation would be  $P_A = \frac{(\Delta Y) (P_Y)}{A}$ . Again we may wish to know what ( $\Delta Y$ ) will have to be if we are given the other three. The equation could be set up as  $\Delta Y = \frac{(A) (P_A)}{P_Y}$ , and the solution would give a minimum ( $\Delta Y$ ) for the profitable use of (A). The practice (A) would not be solved for as it is constant and given in all cases.

The first equation formulated by manipulation,  $P_Y \geq \frac{(A) (P_A)}{\Delta Y}$ , can be shown graphically as in Figure 9, where money costs are shown along the vertical axis and the increment in yield along the horizontal axis. If ( $P_A$ ) is given at  $P_{A_0}$  and the increment in yield ( $\Delta Y$ ) changes from small to large, the minimum price ( $P_Y$ ) of the product decreases, say, from  $\frac{a}{\Delta_0 Y}$  to  $\frac{b}{\Delta_1 Y}$  and down to  $\frac{e}{\Delta_4 Y}$ . Conversely, as the increment in yield is given ( $\Delta Y_0$ ) the price will need to rise as the price of the service ( $P_A$ ) increases to maintain an equality. This price is the minimum for profitability or "break-even" price.<sup>1/</sup>

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<sup>1/</sup> Baker, C. B., op. cit.

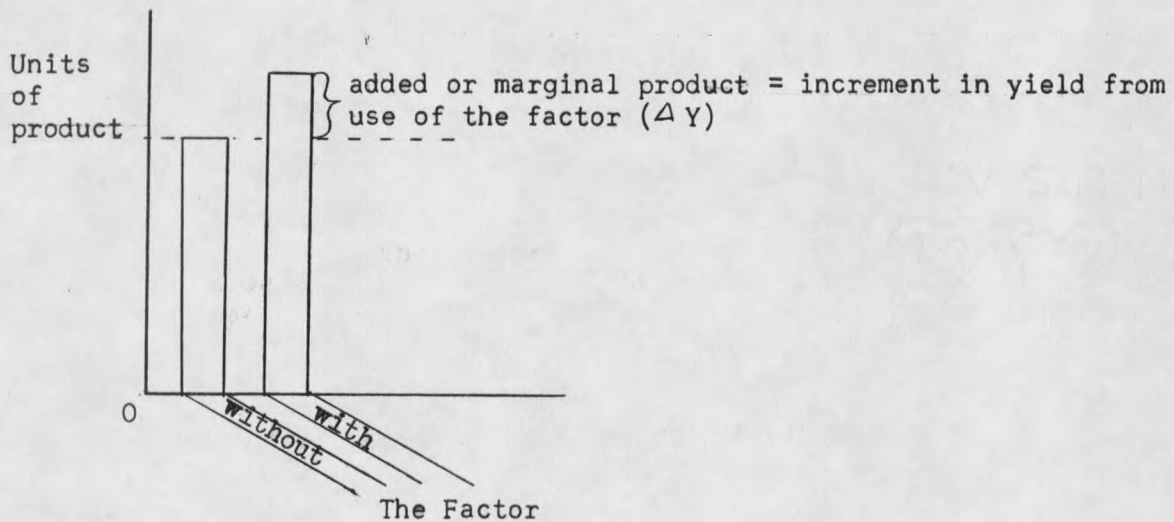


Figure 8. Comparison of the amount of product produced with and without the use of a resource "practice."

Similar expositions could be shown for the other derived formulas  $\Delta Y \cong \frac{(A) P_A}{P_Y}$  and  $P_A \cong \frac{(\Delta Y) P_Y}{A}$ . In the first,  $\Delta Y \cong \frac{(A) P_A}{P_Y}$ , it can be seen that as  $(P_Y)$  increases,  $(\Delta Y)$  can and will be smaller if  $(P_A)$  remains unchanged. When  $(P_Y)$  remains unchanged and  $(P_A)$  increases,  $(\Delta Y)$  will have to be larger to maintain profitability.<sup>1/</sup>

In the second equation,  $P_A \cong \frac{(\Delta Y) P_Y}{A}$ , where the denominator is a constant we would expect increases or decreases in the fraction depending upon whether either quantity,  $(P_Y)$  or  $(\Delta Y)$ , remained fixed as the other increased or decreased respectively. It is possible in this situation to have  $(P_A)$  remain unchanged. Consider that, in proper proportions,  $(\Delta Y)$  increases as  $(P_Y)$  decreases or conversely where  $(\Delta Y)$

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<sup>1/</sup> In general the above cases hold true for the values of all fractions or ratios expressed as fractions. It is readily seen that as the numerator increases and the denominator remains the same the value of the fraction increases. When the numerator remains unchanged and the denominator increases the value of the fraction decreases.

decreases as ( $P_Y$ ) increases. We can, then, apparently solve for the different quantities we may need to know, if sufficient data are available, to determine the profitability of a "practice" under varying price, yield, or cost situations.

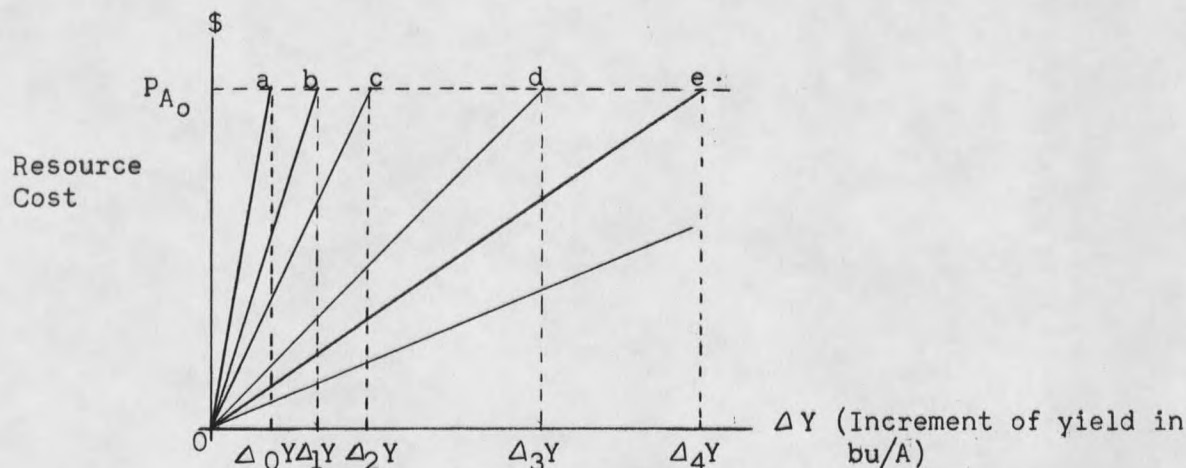


Figure 9. Family of price lines determined from the ratio of input cost to increment of yield.

#### Data Required

The economic advantage from a given application of 2,4-D depends, in part, upon the following relationships: (1) the amount of yield decreases as the (a) intensity and/or (b) area of the weed infestation increases; (2) the rate at which the infestation will be reduced by the application in (a) the current year and (b) in succeeding years; and (3) the effects of incomplete selectivity, i.e., crop yield decrease as a result of spray application. In addition, the operator needs to know (4) the cost of spray application and (5) the crop product price.

From the sum of the effects of the first three of the above relationships the increment in yield of an application of 2,4-D can be approximated.

By adding the fourth and fifth relationships, the economic results can be estimated.

Effect of Weed Competition on Yield of Wheat

From work cited and from the experience of many farmers, there seems little question that crops infested with weeds yield less than crops without weeds. This relationship is illustrated graphically in Figure 10. The operator faced with a given level of weed infestation needs

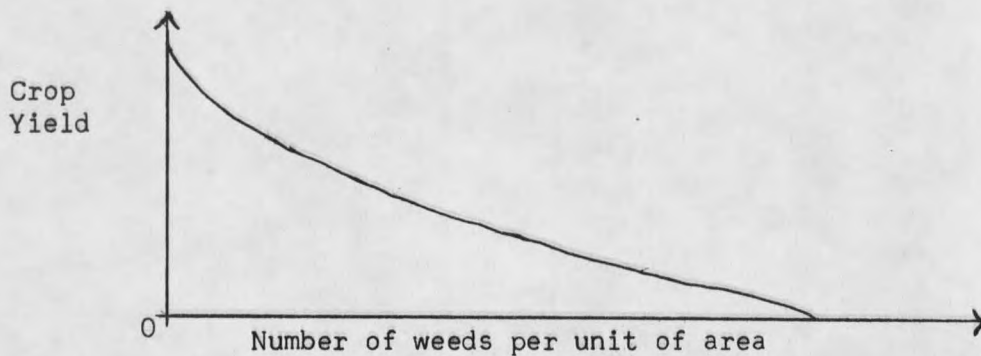


Figure 10. Yields expected as weed competition increases in a given area.

to know whether the expense of a "practice" which will allow him to operate at some lower level of infestation is justifiable. There may be little doubt when the infestation is so great that yields are reduced to near zero. His choice will depend upon more accurate knowledge, however, when infestations are light and nearly full yields are being produced. The use of a weed control "practice" is economically sound only when it frees the productive resources of inhibitions on their productivity -- this perhaps, instead of any independent productivity of its own.<sup>1/</sup>

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<sup>1/</sup> It performs a service in the production process under weedy conditions. See Heady, op. cit., p. 22 for a more complete discussion.

Under field conditions, it is difficult to estimate levels of infestation and the related yields. Infestations are not likely to be uniform throughout the field. (See Figure 17 a and b in the Appendix, page 88). This is particularly true of Canada thistle, as has been pointed out earlier. Yet, a uniform infestation will be assumed to facilitate the first analysis. An attempt will then be made to correct for lack of uniformity. In experimental work, a series of samples from fields of small grains infested with Canada thistles were taken at different levels of infestation. (See Figure 17 d in the Appendix, page 88). This technique could be used by the farmer in his own field where such information is not available.

When yields have been estimated for the different levels of infestations, it is possible to determine the amount of production that can be gained from changing from higher to lower levels of infestation. It is only necessary to subtract the yield at the higher infestation from that at the lower infestation.

#### Effect of 2,4-D in Reducing Weed Competition in Wheat

The application of 2,4-D may give either complete, partial, or no reduction in numbers of thistles. If no reduction is expected, presumably, undoubtedly no 2,4-D would be applied. Most desirable would be the complete eradication from one application, other things being equal. If this were accomplished, no further work would need to be done until a new infestation is encountered.

Since a given application of 2,4-D is usually less than completely effective in the eradication of Canada thistle competition, it is necessary

to determine what level of infestation may be expected to remain after the application. The difference between the yield at the remaining level and the yield at the level at the time of application (less non-selective effect) is the increase in product for that application. Sufficient information should be found, before the application is made, to allow a reasonable choice as to whether this expected increase and averted loss from regrowth, at the expected price, will be sufficiently valuable to at least equal the cost of the application  $\left(\Delta Y = \frac{A (P_A)}{P_Y}\right)$ . The information should include the expected percent of Canada thistle kill, price of the product, and cost of application.

The infestation remaining after spray application can be used as the basis for a decision as to whether an application would be profitable in the next cropping season. In addition to the first year's return from the use of 2,4-D, increments in yield will be forthcoming for a period of years, even assuming no further control measures are taken.

#### Rate of Canada Thistle Regrowth and Spread

Regrowth is reflected in either (1) increased intensity within an area, (2) increased area of infestation, or (3) both 1 and 2. The amount of regrowth (after spray) within an area will be assumed to reduce yields as though it were an equal level of original infestation. Such a yield would be estimated along the curve described in Figure 10, as intensity increases. Also, temporarily, a constant rate of increase in intensity will be assumed throughout the relevant range of infestation. If it is further assumed that thistles remaining after application will increase at the same rate as an infestation that has not been sprayed, the rate

of regrowth would need to be added to the level of infestation remaining after application in making a decision about any given application.

The growth habits of Canada thistle necessitate also data concerning the rate at which the area of a thistle patch will spread. What little evidence is available on this rate comes from work done at the University of Saskatchewan. It was concluded from the work done there that a single small root cutting from one to three inches in length is capable of producing, under favorable conditions, a solid patch 60 feet in diameter in three seasons.<sup>1/</sup> No mention was made of the level of infestation, within the patch formed, in this publication.

A mathematical function of the rate of area increase in relation to radius of the given patch can be found.<sup>2/</sup> When the area of a circle, given by  $A = \pi r^2$ , is differentiated with respect to time, the differential equation is  $\frac{dA}{dt} = 2\pi r \frac{dr}{dt}$ . The average rate of increase ( $\frac{dr}{dt}$ ) in the radius from the above information is 10 feet per year. Since we desire to know how fast the area is increasing when the radius is given, say 30 feet, it can be found by substituting the known values in the differential equation and multiplying both sides by  $dt$  which gives  $dA = 600\pi$ . Since  $\pi \approx 3.14$ ,  $dA \approx 2484$  square feet per year, when the radius in the first year is given at 30 feet.

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<sup>1/</sup> T. K. Pavlychenko, L. E. Kirk, and W. Kossar, Eradication of Perennial Weeds by the Shallow Cultivation Method (Agricultural Extension Bulletin 100, University of Saskatchewan, College of Agriculture).

<sup>2/</sup> It is assumed that the patch is nearly circular.

From field observations it seems quite likely that the outer areas of a developing thistle patch are less densely infested than inner areas which have been established in previous years. (See Figure 17 d page 88) Too, under field conditions the rate of growth of a thistle patch, in size, should be inhibited by competition from the crop. This may, however, be offset by the breaking up and scattering of the rhizomes by tillage implements.

The data available on these factors of regrowth are insufficient for estimating purposes. It will be possible, then, to only point to their possible implications.

#### Selectivity Effect of 2,4-D on Wheat Yield

As pointed out on page 21, wheat yields are sometimes depressed after treatment with 2,4-D. Apparently many conditions such as stage of growth of wheat, temperature, soil moisture, fertility level, etc., influence the effect of 2,4-D on wheat and other plants. Since the contribution of each or any combination of these factors to decreased yields of wheat have not been fully determined, it is impossible to predetermine the exact effect 2,4-D treatment will have on wheat yield. Therefore, for purposes of this study yield depression will be at arbitrary level determined from limited data available.

It was indicated earlier (Table II) that this loss may run as much as 8.3% under weed-free conditions. Insufficient data are available to determine whether this loss can be offset by reduced competition after spraying under heavily weeded conditions, during the initial crop year

by eliminating recoverable competitive effects. It is most likely to be a critical factor when infestations are light.

#### Spray Application Costs

The entrepreneur considering the use of a given application of 2,4-D will probably also have to decide whether (1) he will buy his own equipment or (2) hire a custom sprayer to do the work. The rate for custom spraying will vary with the crop, size of fields, and materials used. The 1955 estimates of the Doane Agricultural Service, for custom spraying ranged from \$1.25 to \$3.00 per acre for spraying weeds, depending upon the rate of 2,4-D used and field sizes involved, with material included.<sup>1/</sup>

If the operator chooses to invest in his own machinery, he will have a wide choice of machines, in various price ranges, from which to choose. The size and type he will choose should at least be partially determined by (1) the length of service required; (2) the amount of area to be covered in a given time; and (3) the expected annual and per acre costs of the machine; and (4) any alternate uses, such as cattle spraying. A ready-built, trailer-mounted sprayer, with a 200-gallon tank, a 4-gallon per minute pump, and a 25-foot boom delivered locally, lists at \$925.00. As an alternative, pump and boom kits, which the operator can mount on a tractor with barrels for supply tanks, can be purchased locally for \$181.00.<sup>2/</sup> These machines will

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<sup>1/</sup> Enclosure in letter to D. C. Myrick from Bert Slatten of Doane Agricultural Service, Inc., January 20, 1956.

<sup>2/</sup> This range of machine costs was given by Mr. Stevens of Owenhouse Hwde., of Bozeman, Montana, personal interview, March 1956.

cover approximately the same area in a given period of time. In addition to the initial cost of the kit type spray equipment, the time and materials necessary to mount the equipment on a tractor would need to be considered. To these actual machine costs will be added the cost of operating labor, chemical (2,4-D)<sup>1/</sup> tractor, and fuel.

When the farmer chooses to own and operate his own equipment, some time and study will also be required in order to operate the machine properly for effective results.<sup>2/</sup>

In addition to comparing costs of owning his own spraying equipment and hiring custom work, the farmer would need to consider the availability of competent labor to use the equipment, as well as other work, such as early haying, which might interfere with the timeliness of spraying. If the farmer chooses to have a custom sprayer do his work, he would also need to have assurance that a custom operator was qualified and would be available at the proper time to get maximum benefits from the spray application. For the purposes intended here, a timely, accurate spray application will be assumed by either method. It has been pointed out in previous work that care in the use of 2,4-D is rewarded. Crops in areas not sprayed grow under competition from weeds. Areas which are overlapped are subject to damage from the spray.<sup>3/</sup>

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<sup>1/</sup> For a complete discussion of chemical costs and measurement, see L. O. Baker, J. M. Hodgson and others, Weed Control In Montana 1956, forthcoming Montana Agricultural Experiment Station Bulletin.

<sup>2/</sup> Ibid.

<sup>3/</sup> D. G. Myrick, "Costs of Weeds and Economics of Control," Proceedings of the Fourteenth Western Weed Control Conference, Tucson, Arizona, March 22-24, 1954, pp. 10-16.

Value of the Increment in Yield

The value of the increment in yield will depend upon (a) the product concerned and its expected price; and (b) the size of the increment in yield. The size of the increment in yield will be, as pointed out previously, a function of the level of infestation and the rate of regrowth that can be expected. The price of the product will depend upon the demand and supply for the product or the on-farm use to be made of it. Prices for small grains and cereals have normally fluctuated over a wide range. Since the data used concerns wheat, its price is the most relevant. With a support price on wheat its price is easily estimated. In some areas the restrictions on wheat plantings have caused an increase in feed grain production. The additional supply has generally caused a decline in price. Still these prices change considerably from year to year and with seasons of the year. The operator should arrive at some reliable estimate of what these prices will be before he can make a reasonably sound decision on what value to place on a given increase in yield.

Statement of Problem

Since an estimate of the size of the increment in yield ( $\Delta Y$ ) is a function of the level of thistle infestation, amount of yield from reduced competition, non-selectivity of the chemical, and the loss that can be averted from allowing regrowth, the operator can, with a given price expectation, find the value of the increased production. He needs only to determine whether this value at any given level of infestation is

$\geq$  (greater than or equal to) the cost of the given application of 2,4-D to determine the lowest level of infestation at which he can "break-even" on the application.

PART II.

EMPIRICAL EVIDENCE

Estimates of the relationship of thistle population reduction to the control measures were obtained experimentally. Most of the actual field work was performed by the personnel of the Agricultural Research Service. Summary data are available in annual reports from 1953 to date. In addition, estimates of the effect of thistles on crop yields were obtained from a survey of farm fields which varied in the degree of thistle infestation. This survey was made during the 1953, 1954, and 1955 cropping seasons. The experiment was performed in the fields of the Montana State Agricultural Experiment Station in the Gallatin Valley near Bozeman.

Growing Conditions in the Gallatin Valley

The Montana State Experiment Station at Bozeman, Montana is located at approximately 46 degrees north latitude and 111 degrees west longitude at an elevation of approximately 4800 feet above sea level. The irrigated farming area in which the Station is located lies generally in gentle slopes of from two to five percent.

The topography and soil vary considerably through the valley. The soil at the Experiment Station is classified as Huffine silt loam. The organic layer ranges from twelve to eighteen inches in depth. This organic layer overlies a brown, sticky, silty clay or clay loam subsoil which in turn overlies a deep gravel bed varying from 2 to 4 feet below the soil surface.<sup>1/</sup>

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<sup>1/</sup> Jesse M. Hodgson, Annual Report Cooperative Weed Control Investigations, Unpublished Report of 1953. Weed Investigations Section, Field Crops Research Branch A.R.S., U.S.D.A, cooperating with Montana State Agricultural Experiment Station and Region 6 of Bureau of Reclamation.

In Figure 1, page 5, the principal farming area of Gallatin County is shown in the semielliptical double cross hatched area. While the actual river valley extends nearly the full length of the county, only the area located in the northwestern part of the county is intensively farmed. This area is ringed by mountains except to the northwest. As a result, low clouds are trapped and the areas along the mountains receive considerably more rainfall than the other parts of the valley.

The average annual rainfall as reported in 1941 varies from 11.86 inches in the northern end of the valley at Three Forks to 17.39 inches at the Experiment Station near Bozeman.<sup>1/</sup> Above average rainfall in a number of years since 1941 has raised the long-time average at the Experiment Station to 18.03 inches annually.<sup>2/</sup> Precipitation in the 1953-55 period is shown in Table III a.

In the irrigated areas the rainfall is generally not a critical factor, although timely rains may contribute when small grains are filling. Growing season precipitation, April through October, averages 9.82 inches.

#### Temperature and Growing Season

Mean monthly temperatures are shown in Table III b. The average length of frost-free period (1901-1953) is 116 days. The frost-free days for 1953, 1954, and 1955 were 120, 149, and 81 days respectively.

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<sup>1/</sup> Climate and Man, Yearbook of Agriculture, 1941 (United States Government Printing Office), p. 956.

<sup>2/</sup> Hodgson, 1953 Annual Report Cooperative Weed Control Investigations, op. cit., p. 6.

TABLE III. (a) ANNUAL PRECIPITATION RECORDS, 1953 THROUGH 1955, COMPARED TO 76-YEAR AVERAGE. (b) TEMPERATURE MEANS, 1953 THROUGH 1955, COMPARED WITH 1901 TO 1949 NORMAL.

	(a)				(b)			
	1953	1954	1955	76-yr. avg.	1953	1954	1955	1901-1949 normal
Jan.	.65	1.10	.54	.91	33.7	21.4	19.3	20.0
Feb.	1.05	.13	1.00	.75	23.5	34.5	19.7	22.8
March	1.04	1.19	1.33	3.51	35.9	26.0	21.9	30.6
April	2.05	.44	3.51	1.69	38.3	43.9	37.2	41.5
May	3.23	1.70	2.70	2.77	46.5	51.7	50.3	49.7
June	3.13	3.70	2.23	2.77	57.9	55.5	56.9	56.9
July	.63	.66	1.55	1.31	68.7	69.4	65.5	67.0
Aug.	.42	1.32	.12	1.18	67.3	64.0	67.6	68.1
Sept.	1.00	1.21	1.11	1.79	59.5	56.5	55.5	54.1
Oct.	1.39	.88	2.04	1.49	49.6	44.1	47.8	44.2
Nov.	2.26	.07	.78	1.10	39.5	40.8	23.45	31.6
Dec.	.64	.07	2.19	.94	29.0	23.7	22.32	23.0
Total	17.49	12.68	19.10	18.03				

Source: Jesse M. Hodgson, Annual Report Cooperative Weed Control Investigations. Unpublished reports of 1953, '54, and '55. Weed Investigations Section, Field Crops Research Branch A.R.S., U.S.D.A., cooperating with Montana State Agricultural Experiment Station and Region 6 of Bureau of Reclamation, p. 6, 6-7, and 10-11 respectively.

Rainfall and Temperature Effects on 2,4-D Effectiveness

Rainfall may be a critical factor when it comes too soon after a spray application. It is believed, however, that 2,4-D may penetrate the cuticle of the leaves in as little as 1 or 2 hours.<sup>1/</sup> It is also possible to have had a prolonged dry season before spraying such that thistles might not be actively growing.<sup>2/</sup>

<sup>1/</sup> Robbins, Crafts, and Raynor, op. cit., p. 195.

<sup>2/</sup> Ibid.

Low temperatures over a period of days prior to spraying may result in increased adverse effects on grain yields.<sup>1/</sup> Temperature may also affect the growth rate of the thistle which seems to partially determine the effectiveness of the spray application.<sup>2/</sup> However, no such unusual temperature or rainfall reports are included with the available data and it will be assumed that they did not occur.<sup>3/</sup>

#### Control of Canada Thistle as Determined Experimentally

##### The Experimental Design and Plot Layout<sup>4/</sup>

A five-acre field on the Experiment Station farm near Bozeman, heavily infested with Canada thistle, was chosen for the test. The entire field was plowed April 25, 1953, and plotted into 30 by 80 foot plots, each nearly 1/18 of an acre. Sixteen control programs were tried, each replicated four times. These programs were assembled into four groups: Group 1, spring wheat under five various chemical and cultural treatments; Group 2, perennial crops; Group 3, rotations; and Group 4, fallow in the initial year.

The plot layout is shown in Figure 11. The plots were randomized within groups. The five programs to be used on the spring wheat were designated A, B, C, D, and E as noted in Figure 11.

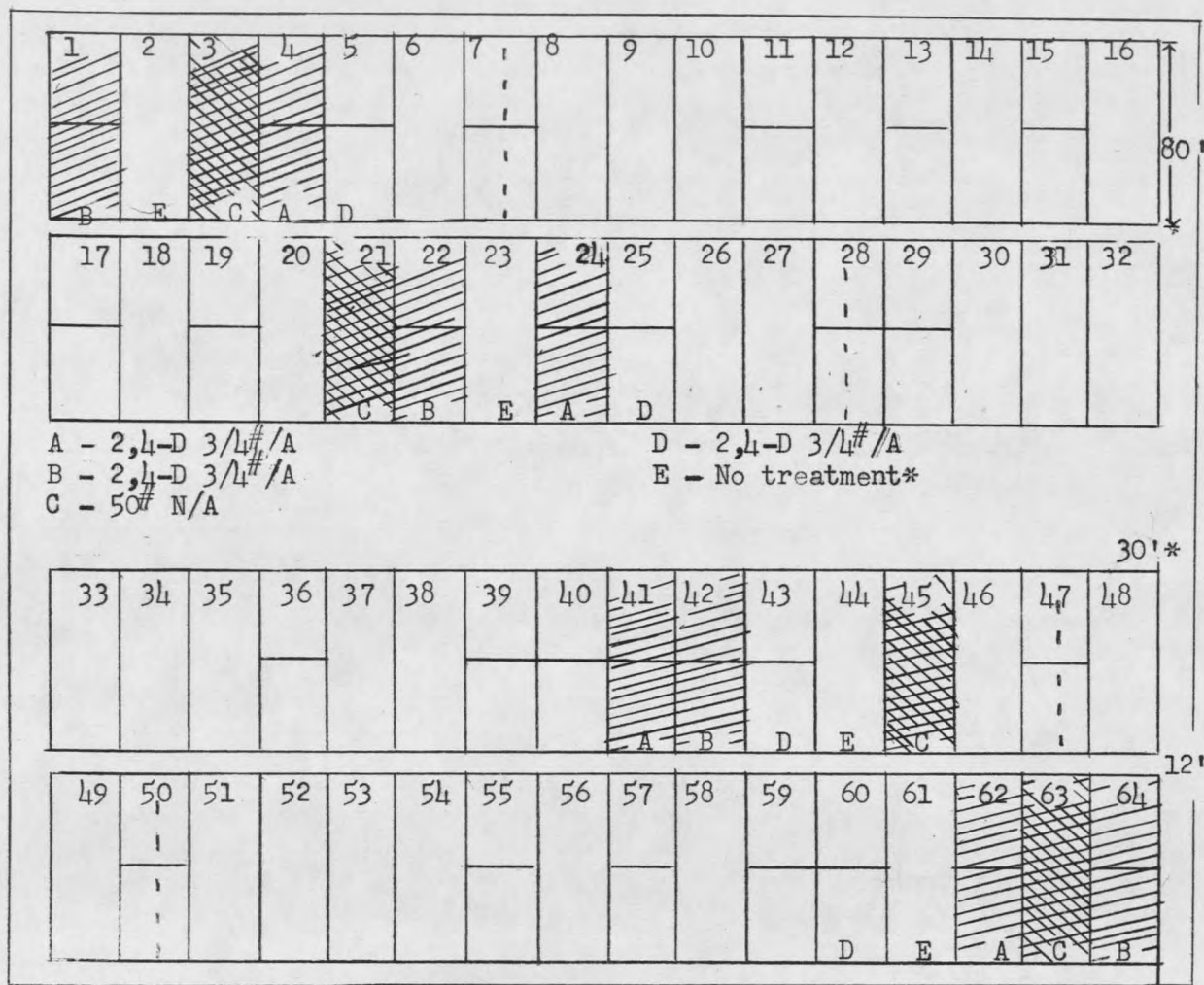
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<sup>1/</sup> Warden, op. cit.

<sup>2/</sup> Robbins, Crafts, and Raynor, op. cit., p. 194.

<sup>3/</sup> This type of research might be more effectively carried out in a greenhouse where the temperature and moisture could be controlled.

<sup>4/</sup> Hodgson, 1953 Annual Report Cooperative Weed Control Investigations, op. cit., p. 18-28.



\*Explanation in text page 53.

Figure 11. Experimental plot layout.

Source: Hodgson, 1953 Annual Report Cooperative Weed Control Investigations, op. cit., p. 23.

A controversy has existed over the effectiveness and selectivity of the ester versus amine formulations. Hence, plots A, B, and D, that were to receive 2,4-D as part of their treatment, were further subdivided into halves. The ester formulation was used on the east half of the 30 by 80 foot plots and amine formulation on the west half.<sup>1/</sup>

Permanent marks were established on both the east and west fences and in the middle roadway so the count areas could be readily found in subsequent years. A steel quadrat, 3 feet square was placed at measured intervals until a total of 10 sample count areas were established in each of the 30 by 80 foot plots. The center area of the plots was chosen for the count areas to avoid, as much as possible, border infestation from neighboring plots. Measurements were designed so five of the thistle count areas would be in the east half and five in the west half of each plot, to facilitate study of the two formulations of 2,4-D.

Other control programs involve duckfoot cultivations and sprays other than 2,4-D on various crops. Rotations of crops, cultivations, and chemicals were also used in various combinations. No attempt will be made here to evaluate measures other than 2,4-D spray on Canada thistle in spring wheat. Brief references to other crops may, however, be made for comparison and support where necessary.

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<sup>1/</sup> In Table IV only the results for 1954 show a consistent difference in selectivity in favor of the ester formulation. No consistent trend for effectiveness is apparent from Table IV.

### Conduct of Experiment

#### Thistle Population Determination<sup>1/</sup>

In the first year, 1953, the cultivation and chemical treatments were delayed, in some instances, to allow good thistle emergence on all plots. The counts were made beginning June 22.

Counts were made only on the shoots emerging from root stocks. Seedlings were counted neither in the initial year nor the following years.<sup>2/</sup> Seedlings are controlled by measures similar to those used for annual weeds. Shoot counts were made in June of 1954 and 1955, prior to spraying, to determine the effectiveness of the previous year's treatment.

#### 2,4-D Application

The single rate of  $3/4$  of a pound of acid equivalent per acre was used in all trials. Water at 20 gallons per acre was used as the carrier. No attempt was made to vary the rate ( $3/4\#$  of 2,4-D acid equivalent of either formulation) of application. Higher rates of 2,4-D increase the adverse effect on wheat and lower rates are less effective in controlling Canada thistle.<sup>3/</sup>

A summary of results is shown in Table IV. Yields and thistle counts are means of four-plot replicates receiving the same treatment unless noted otherwise.

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<sup>1/</sup> Hodgson, 1953 Annual Report Cooperative Weed Control Investigation, op. cit.

<sup>2/</sup> The distinction between the two is made by experienced and trained personnel on the basis of the leaf structure.

<sup>3/</sup> Higher rates have been used at Newdale, Idaho. See Hodgson's 1953 Annual Report Cooperative Weed Control Investigations, op. cit., p. 50.

The single application of 2,4-D was made each year when Canada thistle was in the early bud stage. This early bud stage of growth occurs just after the thistles begin to send up vertical shoots from the rosette formed after emergence. The rosette grows horizontally until it attains a diameter of from 8 to 10 inches. These rosettes tend to suppress other plant growth in the area which they cover. The wheat was in the late tillering or early boot stages of growth at the time of application. During these stages of growth, wheat seems least susceptible to damage from 2,4-D.

Thistle counts were made only once each year. The amount of reduction from a spray application is, therefore, determined at the beginning of next season when only those shoots surviving the winter are of consequence.

Competitive Effects of Canada Thistle on Wheat Yields  
as Determined from Farm Field Surveys

A survey of the farms in the Gallatin Valley was made to determine the competitive effects of various levels of Canada thistle infestations on spring wheat yields. When a farm could be found with a wheat field infested with Canada thistle and permission could be obtained, samples of spring wheat yields were taken at different levels of infestation. The sample areas were 2 by 8 feet, usually 4 drill rows. All sample areas were the same size, 16 square feet. All grain from each 16 square foot plot was harvested, threshed, weighed, and converted to a bushel per acre basis.<sup>1/</sup> The number of thistles in each plot was also counted. The samples with zero thistle shoots were taken just outside the thistle patch along four drill rows. Since thistle patches are usually more

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<sup>1/</sup> Grams of wheat per 16 ft.<sup>2</sup> divided by 100 equals bushels per acre.

dense in their center areas, samples at the desired level of infestation could usually be found by moving inward along the original rows.

TABLE IV. SUMMARIZATION OF PLOT DATA FOR 2,4-D CONTROL OF CANADA THISTLE IN SPRING WHEAT.

Treatment*	Plot <sup>a</sup>	Mean number of thistle shoots per 5 quadrats (45 sq. ft.)			% of 1953 thistle shoot count		yield in bu/acre		
		1953	1954	1955	1954	1955	1953	1954	1955
A Nitrogen and 2,4-D	East	77.75	7	2.5	9.0	3.2	57.98	66.7	52.3
	West	110.25	9	2.25	8.1	2.0	57.82	54.5	50.4
B Nitrogen and 2,4-D	East	134.0	7.25	.5	5.4	.37	50.74	62.95	51.5
	West	108.5	8.25	4	8.1	3.7	55.54	55.5	50.9
C Nitrogen	East	96.0	108.75	188	113.3	195.8	62.83	44.92	25.07
	West	130.5	150.75	251	115.5	192.3		51.7	32.07
D 2,4-D	East	77.25	8	2.5	10.3	3.2	54.84	70.4	44.3
	West	100 <sup>a</sup>	14.7 <sup>c</sup>	4.3 <sup>c</sup>	14.7	4.3	55.21 <sup>c</sup>	60.8 <sup>c</sup>	51.8 <sup>c</sup>
E <sup>d</sup> None	East	106.25	113.5	179.75	106.8	169.2	49.37	49.0	23.9
	West	151.75	194.25	195.25	128.0	128.0		45.5	31.7

\* Nitrogen was used at the rate of 50 pounds per acre; 2,4-D was used at the rate of 3/4 pound per acre.

<sup>a</sup> The east halves were sprayed with the ester formulation, the west halves with the amine formulation.

<sup>b</sup> Numbers per 45 ft.<sup>2</sup> times 0.355 gives number per 16 ft.<sup>2</sup>

<sup>c</sup> The average of three plots as the west half of plot 5 under treatment D was not sprayed in 1953.

<sup>d</sup> Nitrogen fertilizer 50#/A was added to plots receiving treatment E in 1953.

Source: Adapted from Hodgson, 1953, 1954, 1955, Annual Report Cooperative Weed Control Investigations, op. cit., pp. 28, 46, and 39 respectively.

In Table V the wheat yields at various levels of Canada thistle infestations are given. Four samples were taken at each level of infestation in both dryland and irrigated fields. It was assumed that other weeds, if present, were equal in all sample areas of each field, and that the regressive effect on yields was due to Canada thistle infestation only.<sup>1/</sup>

TABLE V. MEAN YIELDS OF SPRING WHEAT AT VARIOUS LEVELS OF CANADA THISTLE INFESTATION.

No. of shoots/16 ft. <sup>2</sup>	1953	1954	1955		
	Field 1 <sup>a</sup>	Field 1 <sup>b</sup>	Field 1	Field 2	Field 3
0	15.99	31.7	36.9	20.45	26.6
1			34.5		
2-5			32.43	16.6	19.5
3-8	13.84	27.6			
20-30	10.57	23.0	25.1	9.7	16.1
40-50				6.5	7.2
45-55	7.12	18.0			
50-60			13.45		

<sup>a</sup>Hodgson, 1953 Annual Report Cooperative Weed Control Investigations, op. cit., p. 30.

<sup>b</sup>Hodgson, 1954 Annual Report Cooperative Weed Control Investigations, op. cit., p. 53.

<sup>1/</sup> It might be argued that as thistle numbers increase, other weeds are like wheat--reduced in number. If so, very light infestations of thistle may appear to give more reduction per thistle than do those in heavier infestations.

Data from Table V are used to plot the field curves in Figure 12. The (x) along the field curves indicate the points for which there are observations. The points (x) on the experimental plot curve were established from the 1954 plot data. The first (1) is the average of thistle and yield data for treatments A, B, and D. The second (2) is the average yield and number of thistle shoots in the east half of the plots receiving treatment E, arbitrarily chosen for the thistle level present. For the third (3) the yield and average infestations were taken from plots receiving treatment C. Since treatments A, B, and D were 2,4-D and the plots receiving these treatments were sprayed in 1954, the correction for spray loss was made to determine the curve for the low levels of infestation. The curve, the uppermost on Figure 12, labeled "experimental plots with 8.3% loss from spray" was thus established.

The curve of Figure 12, labeled "mean" is, at each point, vertically the arithmetic mean of the adjusted experimental plots and 1955 field I.

The percent curve was drawn by assuming a yield of 55 bushels with no thistle competition. Other points along it were determined by the mean percent of decrease at each level of infestation of the field and adjusted experimental curves. Table VI shows yields and percent of full yield in areas at various levels of infestation as determined from the field survey.

While it would be desirable to know the slope and height of the regression curve for different levels of Canada thistle, because of the

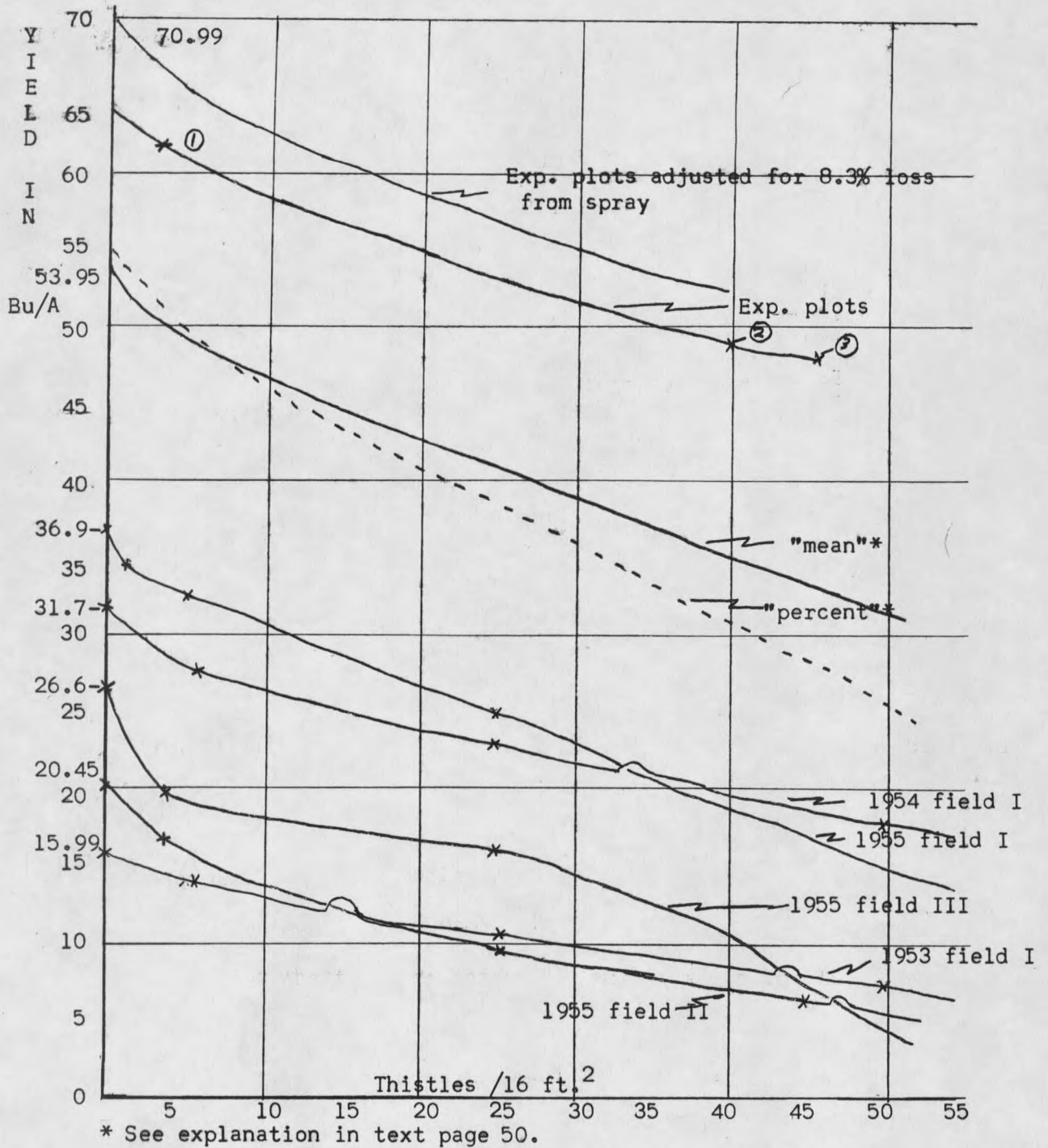


Figure 12. Spring wheat yields associated with various levels of Canada thistle infestation as determined from farm field survey sampling

lack of observations at any particular level and the wide range of yields in the different fields, no attempt was made to develop a statistical regression function. In the low levels of infestation, particularly, say, from one to five thistle shoots per 16 square feet, more observations need to be made. This range of competition may be critical in decision-making. At greater infestations slight errors would be of less consequence. It appears from Figure 12 that an exponential or possibly a straight line function, might best fit the data.

The curve chosen for further analysis represents the mean of the "adjusted experimental plot" and the "1955 field 1" curves from Figure 12. It seems a more likely yield level under the conditions in the Gallatin Valley.<sup>1/</sup> This curve also quite closely approximates the percent curve from the same figure. The percent curve has a steeper slope. It can be noted in the various fields that although the yields varied from near 16 to near 70 bushels per acre, the number of bushels of decrease at any given level of infestation was similar. I.e., irrespective of the height of the curve, the shape or slope is similar. This would tend to increase the slope of the percent curve. If the slope of the percent curve were to continue at its apparent slope, it would intersect the horizontal axis at much less than the 130 shoot per 16 square feet, which reduced yields to near zero in barley (see next paragraph). The

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<sup>1/</sup> It might be argued that the fields which were sampled should be representative of the valley. However, a yield of 53.95 bu/A on well-managed, irrigated land should be more likely than yields of 20 or 30 bushels. Too, some of the sampled fields were dryland.

mean curve would, by maintaining its apparent slope, extend to the infestation level of nearby 130 shoots per 16 square feet. This assumes that regressions of wheat and barley on Canada thistle are similar.

#### Regression in Barley

Although the available data for wheat does not go beyond 60 thistle shoots per 16 square feet, a patch of thistle in a field of barley was found to have 138 thistle shoots in a single 2 by 8 foot area.<sup>1/</sup> The yield of barley in this 16 foot square area was 12 grams, about 1.5 bushels per acre. A sample in the same field from an uninfested area yielded 61.5 bushels per acre. This small yield would not pay the harvesting cost with barley prices in their normal range. While it is unlikely that an operator would allow an entire field to become so heavily infested, some patches may approach it.

#### Empirical Analysis

##### Yield Increases from First Application of Spray

Treatments D and E would have been logical comparisons since treatment D was wheat after wheat with 2,4-D at 3/4 pound per acre and no nitrogen, and E was wheat after wheat with neither 2,4-D nor nitrogen. A change in original plans resulted in 50 pounds of nitrogen per acre in 1953 for plots receiving treatment E. As a result, treatments E and C were identical for 1953.<sup>2/</sup> Since treatments A and B included both

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<sup>1/</sup> Higher levels of infestation have apparently not been reported.

<sup>2/</sup> For complete details on original treatment plans and changes therein see: Hodgson, 1954 Annual Report Cooperative Weed Control Investigation, op. cit., pp. 40-51.

TABLE VI. PERCENT OF YIELD AT VARIOUS LEVELS OF CANADA THISTLE INFESTATION.

SHOOTS PER 16 SQUARE FEET								
Range	0	1	2-5	3-8	20-30	40-50	45-55	50-60
mid-range	0	1	3.5	5.5	15	45	50	55
	70.99		67.9			48.3		
	36.9	34.5	32.43		25.1			13.45
	31.7			27.6	23.0		18.0	
	26.6		19.5		16.1	7.2		
	20.45		16.6		9.7	6.5		
	15.99			13.84	10.57		7.12	
Total	202.63		136.43	41.44	84.47	62.0	25.12	13.45
*N	6	1	4	2	5	3	2	1
Mean	33.77	34.5	34.11	20.72	16.89	20.66	12.56	13.45
**Total of N at zero shoots	202.63	36.9	154.94	47.69	131.64	118.04	47.69	36.9
Mean at zero shoots	33.77	36.9	38.73	23.85	26.32	39.34	23.85	36.9
% of yield at zero shoots	100	93.49	88.07	86.87	64.17	52.51	52.66	36.44

\* Number of observations at various levels of infestation.

\*\* The sum of corresponding yields at zero shoots.

nitrogen and 2,4-D on wheat after wheat, the results from plots receiving treatments A and B can be compared with those receiving C and E in 1953.

The mean yield of plots receiving treatments A and B from Table IV is 55.52 bushels per acre. For plots which received treatments C and E, the mean yield is 56.1 bushels per acre. With only 0.58 bushels per acre difference in yield means, almost intuitively one is led to believe that there is no significant difference.

The statistical test used gave 95% confidence that there is no significant difference in the true means. The "F" value for an analysis of variance test, which assumed that the design was not greatly different from a random design, was 0.017 with the critical "F" value of 3.1.

Neither does this completely support the proposition that an application of spray will reduce yields by 8.3%. Available data do not give the amount of loss from competition that can be averted. Losses from competition prior to spraying are irrecoverable. It is assumed that enough loss can be averted after spraying, at the levels of thistle infestation (approximately 40/16 ft.<sup>2</sup>) involved in the experimental plots in 1953, that in the first year of spraying, yields are equal in sprayed and unsprayed areas.<sup>1/</sup> It should be noted that the plots in which the trials were made were at a high level of fertility and had been seeded to wheat as early as was possible in the spring. Results under other conditions might be different when wheat had less opportunity to be competitive to thistle growth.

The result of applying 2,4-D is apparently reflected in an increase in yield which results from the reduced number of thistles with which the next year's crop will have to compete. The mean number of thistle shoots per 16 square feet on plots receiving treatments A and B prior to spraying in 1953 was 38.2. On plots receiving C and E treatments the mean number of thistle shoots per 16 square feet was 42.99 for 1953. In the spring of 1954, before a spray application, the thistle shoots were again counted. The results are tabulated in Table IV.

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<sup>1/</sup> This may not always be true. It was found in a field of barley, where a strip had not been sprayed, that yields in the sprayed areas were nearly twice as great as yields in the skipped area. The barley was dryland, however, where moisture may have been critical and thistles were as thick as 130 per 16 square feet.

The shoots on plots that received treatments A and B in 1953 averaged 2.84 shoots per 16 square feet, according to the count made the spring of 1954. This is only 7.43% of the number (38.2) of shoots present in the same areas in the spring of 1953. In plots that received treatment D (2,4-D and no nitrogen) 12.8% of the 1953 count remained in 1954. The mean percent of the 1953 count of thistle numbers remaining in 1954 was 10.11% of the 1953 count on the same plots. The percent of thistle reduction for the first year spray application, then, ranged from 92.57% in plots that received nitrogen and 2,4-D to 87.2% for those receiving 2,4-D only, an average of 89.89% reduction of thistle shoots for a single spray application of 3/4 pound of 2,4-D per acre with 20 gallons of water per acre as carrier.

#### Expected Increase in Yield

The increase in yield from a single application of 2,4-D may be largely observed in the second crop year. Thistles have apparently been reduced from 38.2 shoots to 2.84 shoots per 16 square feet. Wheat which would yield 53.95 bushels per acre, under weed-free conditions, would produce approximately 35.4 bushels per acre when competing with a thistle infestation of 38.2 shoots per 16 square feet. The same crop might be expected to yield 50.4 bushels per acre when competing with 2.84 shoots per 16 square feet, if the "mean" curve in Figure 12 represents the response to thistle infestation. The increase in the second-year crop from applying 2,4-D would, then, be approximately 15.0 bushels per acre.

The assumption is implied that the field would give the same yield in both years, other things being equal. This is probably not a reality in field conditions but is convenient to facilitate calculations and may be closely approximated under irrigation.

#### Yield as Determined Experimentally

The mean yield in 1954 of all plots treated with 2,4-D in 1953 was 61.80 bushels per acre. For those not so treated, it was 47.78. No attempt was made to determine in these plots loss estimates from non-selectivity. The difference was 14.02 bushels per acre without any loss from spray accounted for. Table VII summarizes an analysis of variance of the second year crop on plots that were sprayed in both "year one" (1953) and "year two" (1954). In 1954 the plots receiving only 2,4-D had a slightly higher mean yield than did those receiving both nitrogen and 2,4-D. Also the means of treatments C (nitrogen 1953 and 1954) and treatment E (nitrogen in 1953, and none in 1954) are similar in 1954. Because of this, it is assumed that the effect from nitrogen in this field was negligible. In addition, the plot distribution is assumed to be approximately random. Treatments A, B, and D, as a group, were tested against treatments C and E, as a group.

#### Determination of "Net Effect" from Spray in Year of Spray

Under weed-free conditions, loss up to 8.3% may be experienced from non-selectivity of 2,4-D. This can be interpreted to mean that this loss is experienced by wheat that is sprayed at any level of infestation and is shown in Figure 13 as line AB.

TABLE VII. ANALYSIS VARIANCE FOR THE SECOND YEAR OF SPRING WHEAT, INFESTED WITH CANADA THISTLE, TREATED WITH 2,4-D IN TWO CONSECUTIVE YEARS.

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square	"F" Value
Among plots	1	902.93	902.93	$F = \frac{902.93}{81.39}$
Within plots	17	1385.82	81.39	=11.09*
Total	18	2288.75	-----	

\*Significant at the 1% level as the critical "F" value is 8.4.

It is also estimated that at 38.2 thistle shoots per 16 square feet this 8.3% loss from non-selectivity is offset by increases in yield from reduced competition after spraying, in the same year. This establishes point D in Figure 13. At zero thistle shoots per 16 square feet, no increase is expected since no competition is present to be reduced. Therefore, 0(zero) is another point in the relationship. If a linear relationship exists, the line OD, gives the predicted increase from reduced competition at various levels of thistle infestation. Points along this line can be found by equating the ratio of the given thistle infestation to 38.2 with the ratio of the expected percent increase to 8.3% and solving for the expected percent increase. For the new level of infestation the calculation would be set up as follows:  $2.84/38.2 = \%$  increase/8.3%. The expected percent of increase is found to be 0.61%.

Since at 38.2 thistle shoots per 16 square feet the opposing effects are equal, the net effect is zero. The line AE is the net effect and is, at any point, the algebraic sum of the corresponding vertical points along

lines AB and OD. For example at the new level of infestation, 2.84 shoots per 16 square feet, faced in "year two," the predicted increase is 0.61%. This, added to the negative 8.3%, gives a net effect of a negative 7.69%. The actual numbers of bushels lost would be a function of the expected yield. The more productive the producing system, the larger the loss, at any given percent of loss and level of infestation. If the loss from spray were some percent more, say 10%, or less, for instance 6%, the line AB would be expected to shift with increases or decreases from spray.

A parallel line is predicted because the algebraic sum of the 8.3% predicted increase at 38.2 shoots per 16 square feet and the lower 6% loss from spray give a positive net effect of 2.3% at the infestation rate of 38.2 shoots per 16 square feet. This is illustrated by the dotted line EG in Figure 13. The new infestation, at which the net effect is zero, along FG, is now closer to the origin at approximately 27.5 shoots per 16 square feet. This is consistent with the logic that if any increase is forthcoming and the percent of yield loss from spray decreases, a "break-even" in physical terms would be expected at a lower infestation rate. The opposite would be true if loss from spray were greater than 8.3%. The yield would be increased in the year of spray if infestations were greater than the level at which the net effect is zero.<sup>1/</sup> This is illustrated in Figure 13 as the "net effect" line AE is extended above the axis.

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<sup>1/</sup> See footnote <sup>1/</sup> page 55.

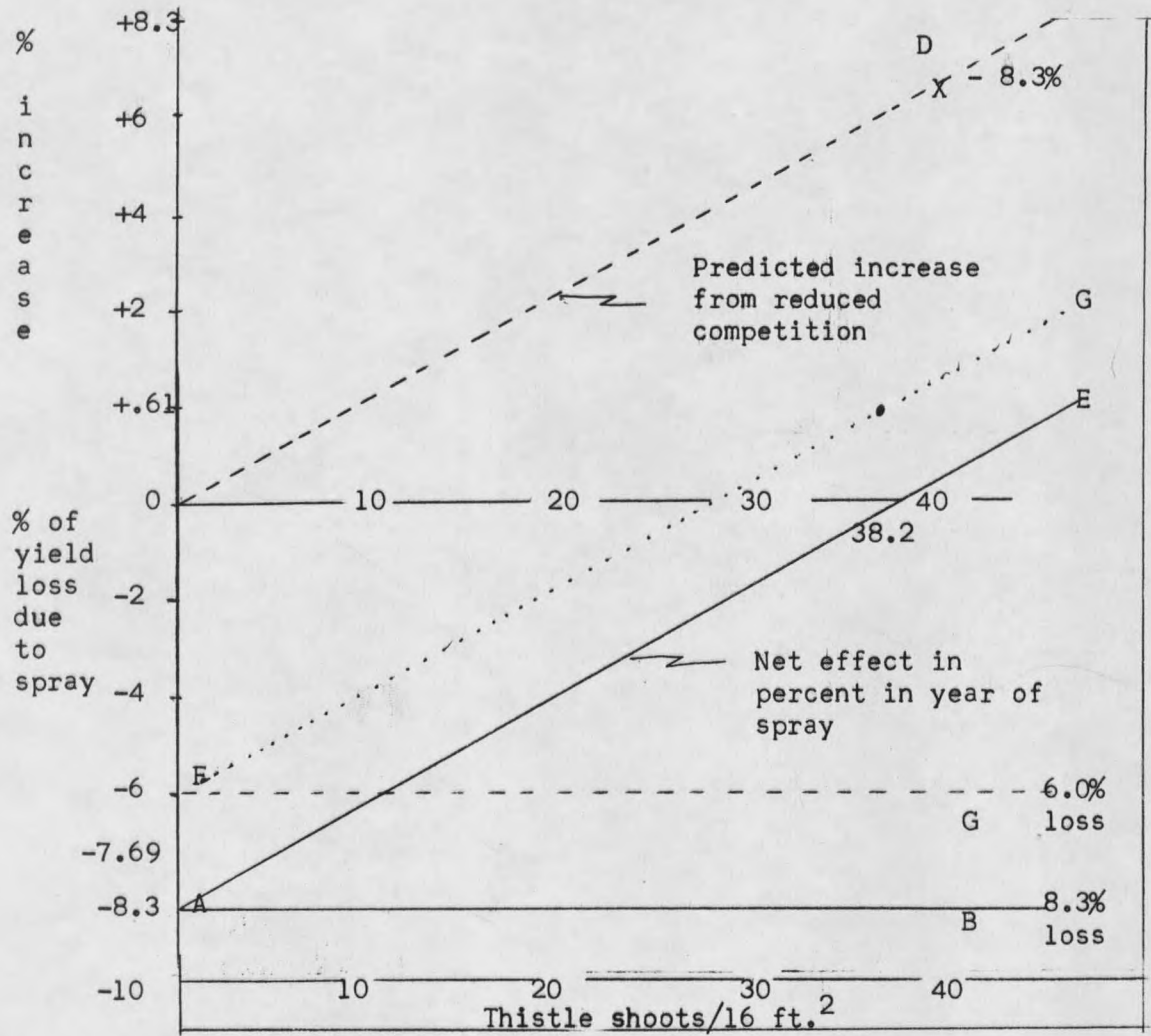


Figure 13. The "net effect" on wheat yield from the opposing effects of reduced competition and non-selectivity of spray resulting from an application of 2,4-D spray at 3/4 pound acid equivalent per acre, in the year of the spray application, at various levels of thistle infestation.

Had the plots, in "year two," treated with 2,4-D not been treated, the expected yield would be 66.5 bushels per acre. The difference would then have been 18.72 (66.5 minus 47.78 bushels per acre). This is larger

than the 15.0 expected for the hypothetical crop, because the level of yield is also greater.<sup>1/</sup>

#### Yield Increase from Spraying the Second Successive Year

Since all the thistles were not killed with the first application of 2,4-D, a new decision is required in the second year as to whether or not to spray again. The new level of thistle infestation has already been estimated to be 2.84 shoots per 16 square feet on plots which received the treatments A and B (3/4 pound 2,4-D per acre). At this level of infestation, the "mean" curve of Figure 12 shows a yield, if no spray were applied, of approximately 50.5 bushels per acre. An estimation of the loss from non-selectivity, at this level of infestation was 7.6% or 3.88 bushels per acre. This loss would be sustained on the second-year crop. The increase in yield would be forthcoming in the following year (or in this case the third year), after further reduction in thistle numbers.

Referring again to Table IV, it can be estimated that thistle numbers on plots receiving treatments A, B, and D (2,4-D two consecutive years) were reduced to an average of 0.95 shoots per 16 square feet. On plots A and B, which received both nitrogen and 2,4-D the two previous years, the thistle population was reduced to a mean of 0.82 shoots per 16 square feet. On plot D, which had received only 2,4-D, the mean number was 1.2 shoots per 16 square feet. Eight of the sixteen (16) half plots receiving treatments A and B had no thistles remaining

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<sup>1/</sup> From Figure 12 we see that yields at various infestation levels are decreased by similar numbers of bushels. The 3.72 increase may again indicate that the non-"recoverable" loss to spray was less than 8.3%.

in the count made the spring of 1955. By the same count, three of the six half plots receiving treatment D had no remaining thistles. I. e., each treatment had reduced the thistles to zero in 50% of the half plots. Only in plot 24, under treatment A, were both halves free of thistles in the 1955 count. Otherwise, only the east or only the west half were thistle-free in any given plot.

The mean percent of thistle shoots remaining in 1955, in plots which had received 2,4-D, was 2.64 of the 1953 count. For those receiving treatments A and B, it was 2.14%; for treatment D, 3.8%. Two successive years of spray with 2,4-D had apparently decreased thistle numbers by 97.36%.

The thistles remaining after two applications in 1955 were 33.45% of those remaining in 1954 after one application. At 0.95 (mean number of shoots remaining on plots receiving treatments A, B, and D) shoots per 16 square feet, the "mean" curve in Figure 12 would predict a yield of 52.0 bushels per acre, an increase of 1.6 bushels per acre in the third ("year three") crop from the spray application if used the second year. This 1.6 bushels is less than the expected 3.88 bushel loss expected in the second or "year two" crop, if sprayed. The decision whether to spray in year two will now have to be determined from how much loss can be averted. A net loss of 2.28 bushels per acre now seems apparent if spray is used at this level of infestation.

#### Spray Effect on Thistle Population Increase

Any decision not to spray in "year one" entails the loss of the increase in yield that might be forthcoming in "year two." The increase

comes from two factors: (1) reducing the existing thistle population and hence (2) the base from which the thistle population can increase. Under field conditions, an increase in thistles will occur in both intensity and area of infestation. (See Figure 17, page 88) A decision not to spray, in a given year, will mean that the following years' crops will be smaller than the current year's crop by the amount of loss due to increased competition. The loss averted is the reduction in yield from the expected increase in thistles.

Shown below in Figure 14 is the increase in population intensity, as determined experimentally, when the initial infestation is approximately 43 thistle shoots per 16 square feet. Curves from other, lower, levels

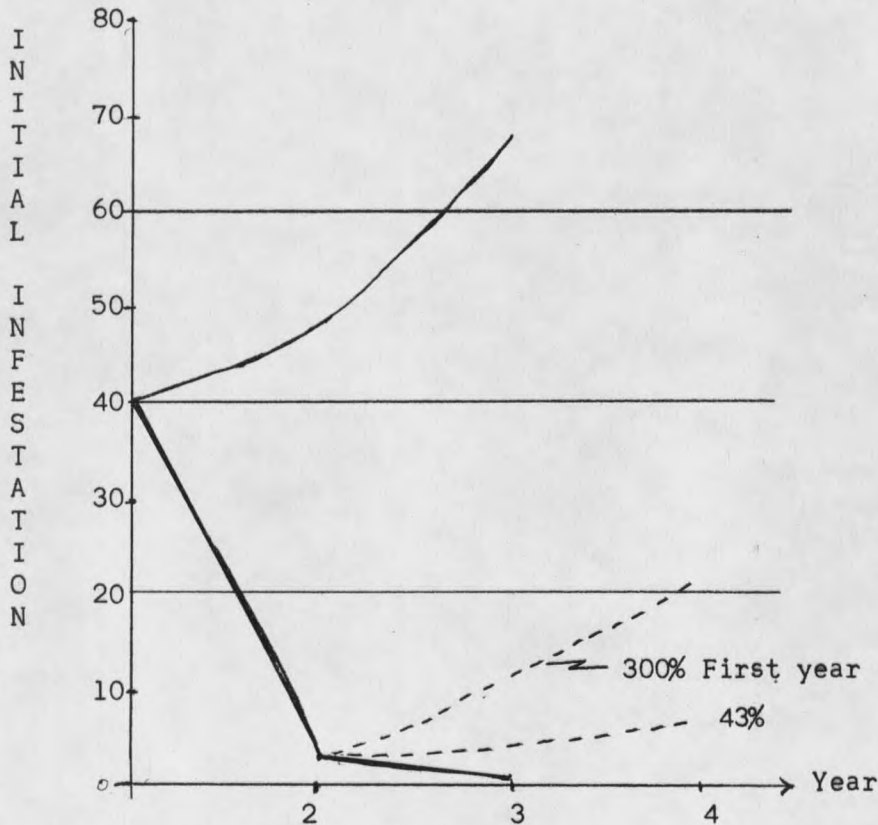


Figure 14. The increase of thistle population when uncontrolled.

of infestations are only suggestive. No evidence is available for such estimates. A rapid increase might come from low levels of infestation.<sup>1/</sup> The upper curve is drawn from the mean of the infestations on plots C and E. These are the plots which did not receive 2,4-D. (See Table IV.) The initial infestations on plots receiving treatments C and E were approximately 43 shoots per 16 square feet: on plots receiving treatments A, B, and D, approximately 38 shoots per 16 square feet.

However, the figure is arbitrarily drawn with an initial infestation of 40 shoots per 16 square feet. The broken lines represent possible increases in infestation. Their slopes and shapes are unknown, but are of importance for decisions as to whether to spray in a given year or to wait until a future date.

In the first count of thistle shoots, made in 1953, the plots which were to receive treatments C and E (neither received any 2,4-D) had a mean of 42.999 shoots per 16 square feet. Two years later, the mean number of shoots in the same areas was 72.24 per 16 square feet, an increase of 68.0%. This is an average increase of 34% per year. The first year gave an increase of only 17.09%, to bring the level to 50.35 shoots per 16 square feet. This 50.35 level was increased by approximately 43.47% in the second year. The information in Table IV might suggest a somewhat faster rate of increase where nitrogen is applied.

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<sup>1/</sup> Pavlychenko, Kirk and Kossar, op. cit.

Assuming an average increase of 34% per year in thistle shoot numbers, an infestation now of 38.4 shoots per 16 square feet would, by next year, be increased to 51.46. The yield level, according to the "mean" curve would be only 31.0 bushels per acre with 51.46 shoots per 16 square feet. This additional loss of 4.4 bushels per acre, added to the 15 bushels increase which would have been forthcoming in "year two," if spray had been used in "year one," gives 19.4 bushels per acre greater yield in "year two" than if spraying had not been done in "year one." While this loss aversion may not be critical in high levels of infestation, it may be the deciding factor at low levels.

The data for rate of thistle increase relate to an initial infestation of approximately 40 shoots per 16 square feet. It is risky to assume that the rate of increase would be the same from, for instance, only one or two shoots per 16 square feet. It might well be that where only one or two shoots are present, they might be increased by two or three times in one year. (See page 34)

Suppose that the thistle infestation of 2.84 shoots per 16 square feet, that remains in "year two," increases by 100% to 5.86 shoots per 16 square feet instead of by 34% to 3.81 per 16 square feet. The difference in yield at these two levels of infestation is one (1) bushel per acre. Too, since the yield at 0.95 shoots per 16 square feet (when a 66.55% reduction is expected) is 52.25, the total productivity of the second spray application would be 3.45 bushels. Rates of even more than 100% may not be unreasonable.

In the work done at the University of Saskatchewan, it was concluded that a solid patch 60 feet in diameter could be produced in three seasons' growth from a single piece of rhizome. (See footnote 1, page 34). This publication included a picture of one-half the root system from the cutting. Along one stem, within a distance 8 feet from the original shoot, 5 new shoots had emerged by the end of the second crop year.<sup>1/</sup> An even higher rate of recovery, or reinfestation may occur. For example, a 300% rate of increase would increase 2.84 shoots per 16 square feet to 11.36 shoots per 16 square feet. At this level the yield would be 46 bushels per acre, and the increment of yield of the spray application would be 6.25 bushels per acre. Lack of information, at critical levels of infestation, reduces the reliability of estimates for increments of yield from a spray application.

#### Economic Criteria for Decisions

The increment in yield ( $\Delta Y$ ) from a given spray application is a function of the two variables plus the loss in yield that can be averted in the next year's crop by spraying in the current year. The first variable is a loss or gain from the "net effect" of spray non-selectivity and reduced competition in the year of spray application. The amount of loss or gain, in turn, depends on (a) the severity of non-selectivity and (b) the productivity of resources with which the sprayed crop is grown. The second variable is a gain in yield, in the second year, from the reduction

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<sup>1/</sup> Pavlychenko, Kirk, and Kossar, op. cit.

in thistle infestation. The amount of gain, in turn, depends on (a) the bio-chemical effectiveness of the spray and (b) the amount of thistle infestation left in the sprayed crop. The loss in yield that can be averted is a function of the rate of reinfestation from the remaining level of infestation. As pointed out previously, the "net effect" from spray, negative or positive, will occur in the year of application. The main increase in yield will come the following year, after thistles are reduced in number.

#### "Net Effect" in Terms of Bushels per Acre

In Figure 13 the "net effect" of spray, in the year of spray, was shown in terms of percentages of increase or decrease in the expected yield. To the operator who is making decisions, these figures can be converted to bushels when the expected yield is estimated. In part A of Figure 15 the bushel loss is shown for a crop yielding 53.95 bushels per acre. The first, or dotted line represents the net effect of spray (in year of spray) on the 53.95 bushel per acre crop used in previous illustrations.

The reader should note that if the expected yield or percent loss from non-selectivity were greater, the "net effect" would cause larger bushel losses at any given level of infestation. I.e., the height of the curve would be lower.

#### Increase in Yield from Reduction of Thistles

In Figure 12, it can be seen that the maximum increase in yield that would be expected, if one application of 2,4-D were 100% effective

in controlling the Canada thistle, at any given level of infestation, would be the vertical distance from the "mean" curve to a horizontal line at the 53.95 bushels per acre level.

In part B of Figure 15 shown as a dotted line, is the curve indicating a 100% reduction in thistles. It is an inverted form of the "mean" curve of Figure 12. Any given point on the "100% reduction curve" is the numerical difference between the "mean" curve and 53.95 bushels per acre. Depending upon conditions such as weather, temperature, soil fertility, or first or second year of spray, the percentage of reduction can vary from zero to 100%. The curves shown are only representative of all those which are possible. The 66.55% curve represents the experimental results from spraying the thistles which remained after one application of spray. The 90% curve is approximately the percent of reduction that occurred from the first application of spray. The vertical height of the curves represent the expected increase at any given level of infestation in the crop yield for the year following spray.

#### Total Increase in Yield

The increase in yield for the year of spray and the following year is the algebraic sum of the heights of (1) the "net effect" curve for the expected yield in the spray year and (2) the expected yield increase in "year two" from a given percent of reduction in the number of thistles which are estimated to exist at the time the spray application is to be made. It should be noted that the bushel increase in yield would be the same for any given yield if the percent loss from spray and percent reduction were the same.

For example, suppose the operator wishes to know what the increase in yield will be if he sprays a crop with an expected yield of 53.95 bushels per acre which is infested with 20 thistle shoots per 16 square feet. He also expects a 90% reduction in thistles and an 8.3% loss from spray. Reading vertically downward from the 20 shoots per 16 square foot infestation level in Figure 15 to the point where this line intersects the "net effect" line and then horizontally across to the bushel axis, he would expect a "net effect" of 2.25 bushels. Reading upward from the 20 shoot level to the intersection with the 90% reduction curve and then again horizontally to the bushel axis, he would expect a 10-bushel increase in the following (second) year's crop. The algebraic sum of the two values thus found is 7.5 bushels. This increase alone would probably encourage his decision to spray.

#### Averted Loss

To the sum of parts A and B, however, we need to add the amount of loss that can be averted from checking the increase of thistles. The amount of loss averted, when the initial infestation is 38.2 shoots per 16 square feet, is estimated to be 4.4 bushels per acre. This averted loss is figured for the 53.95 bushels per acre crop yield. It would not change if the percent of expected reduction changes, for it is assumed that rate of infestation is stopped if spray is effective.

Given a 90% reduction in the initial infestation, the remaining infestation is 2.84 shoots per 16 square feet. Previous studies (see page 34) suggest rates of increase of between 100% and 300% at such low

infestation levels. Assume a 200% increase. This would increase the number of shoots per 16 square feet to 8.52. The corresponding yield would be 47.3 bushels per acre; the averted loss, 3.1 bushels per acre. We have thus established two points on the averted loss curve. A third point would be at 0 (zero), for if there were no thistles there should be no increase.

These points are shown connected by a free-hand curve in part C of Figure 15.

#### Increment of Yield

The sum of the heights of the curves from part A, the curve chosen in part B and the curve in part C give the increment of yield in part D. Assume the 66.55% curve from part B. This is the percent of reduction found experimentally from spraying the 2.84 shoots per 16 square feet in "year two" (a possible critical year and level of infestation). The sum of the parts A, B, and C at the 38.2 shoots per 16 square foot level is 13.6 bushels per acre. At the 2.84 shoots per 16 square foot level it is 0.6 bushels per acre.<sup>1/</sup> A third point would be on the vertical axis at -4.47 bushels per acre.

#### Product Price and Resource Cost in Decision Making

The sum of (1) the net increase in yield for "years one and two" plus (2) the gain from averted loss in "year two" is the increment of yield ( $\Delta Y$ )

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<sup>1/</sup> It can be noted that our assumption of linearity in the "net effect" curve here gives 0.12 bushels per acre less total increment than if a calculation with the slightly lower yield at 2.84 shoots per 16 square feet had been made.

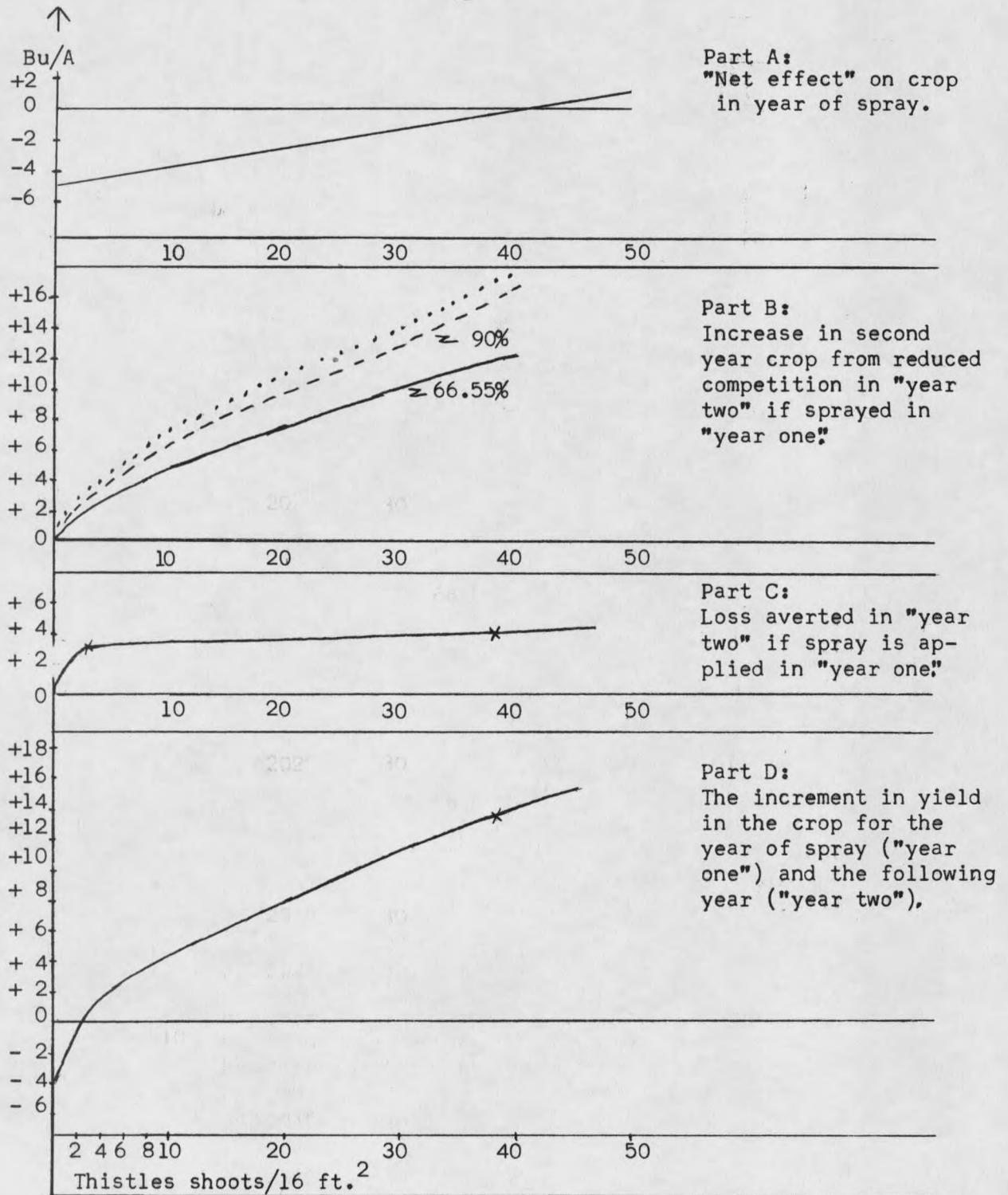


Figure 15. The increment in yield ( $\Delta Y$ ) for spray applied in a given year as the sum of the "net effect" in the year of spray, increase in yield from reduced competition the year after spray, and the loss from added competition which can be averted if the spread of thistles is controlled by spraying.

for an application of 2,4-D. Since it can be determined what the increment will be, it is possible to calculate the maximum cost which can be met for a spray application, when the price of the product is known. It is also possible to calculate the minimum price the product will have to be if the yield-increment and cost of spray is known. Or, finally, given (support) prices on wheat and somewhat standard rates for custom spraying, the operator can calculate the minimum increment in yield he will have to have to get to at least "break-even" on a spray application. Since the increment in yield is a function of thistle numbers, he will finally want to know the minimum level of infestation at which any of these "break-even" points will be met.

Assume a wheat price of \$2.00 per bushel and a cost of spray application of from \$1.00 to \$3.00 per acre. The formula for the required increment of yield ( $\Delta Y$ ) is given by  $\Delta Y = \frac{A (P_A)}{P_Y}$ , where A = the practice,  $P_A$  = the cost of the practice and  $P_Y$  = price of the product. The "practice," a single application of 3/4 pound of 2,4-D per acre, is one and can be dropped in calculation. Therefore we have  $\Delta Y = \frac{P_A}{P_Y}$ . If  $P_A$  varied from \$1.00 to \$3.00 in \$0.50 units, the costs can be set up as \$1.00, \$1.50, \$2.00, \$2.50, and \$3.00. These costs divided by a \$2.00 price for wheat ( $P_Y$ ) give 0.5, 0.75, 1.0, 1.25, and 1.5 respectively as the ( $\Delta Y$ ) which need to be forthcoming to "break-even" on an application of 2,4-D. Similar calculations can be made if the  $P_Y$  varies over a range. The results are shown in Figure 16.

The price rays shown are only representative of an infinite number of such rays that could be shown as the price of wheat may be at or between

any of those shown. The minimum level of infestation can be found in the second (upper left) quadrant by dropping a vertical line to the infestation axis from the intersection of a horizontal line from the minimum ("break-even")  $\Delta Y$  found in the first quadrant.

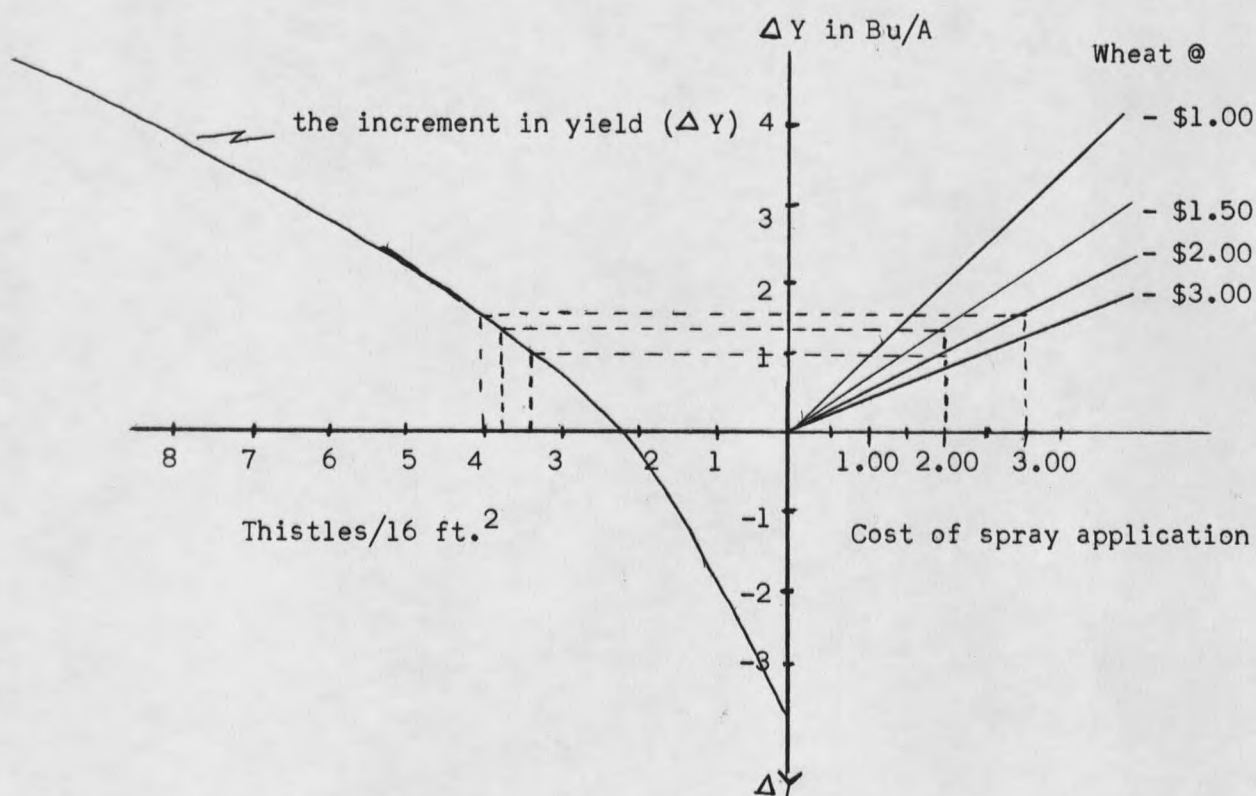


Figure 16. The "break-even" level of thistle infestation at various wheat prices and costs of spray application.

These calculations rest on the ( $\Delta Y$ ) curve established in Figure 15 (part D). Solutions are given for three different levels of infestation. They represent only a few of the many possible situations that could exist. It can also be seen that if the  $\Delta Y$  curve were higher or lower the "break-even" infestation would be different for any given price-cost situation.

From Figure 16, it can be seen that the increment in yield times the expected price will give the amount the operator can afford to pay for spray at any given level of infestation. As the price of the product or the amount of infestation increases, the operator can afford a greater cost for a spray application. A decrease in either product price or thistle infestation would decrease the amount one could afford to pay for spray. If the increment in yield decreases, the price of the product would have to increase, at any given cost of application, to maintain a "break-even" return. The price of the product would also have to increase, if the increment in yield remained fixed and the cost of spraying increased, to maintain a "break-even" relationship. Part of the increase in price might be forthcoming from the value of a weed-free product in the market.

PART III

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Conclusions

The preceding analysis is concerned with the increment in yield from spraying wheat in (1) the year of spray and (2) the following year. This increment in yield ( $\Delta Y$ ) is some function of the level of infestation. Hence, the attempt was made to determine at what level of infestation the increment of yield was sufficient, at a given price of wheat, to be equal to or greater than the expected cost of application.

For a crop that would yield 53.95 bushels per acre under weed-free conditions, and wheat at \$2.00 per bushel the operator could afford to spray, at the rate of  $3/4$  pound per acre, a thistle infestation of from 2.6 shoots per 16 square feet and up if a spray application cost \$1.00 per acre; 3.6 shoots per 16 square feet and up if the cost of spray application were \$2.00 per acre. If these levels of infestation were sprayed, with an expected reduction of 66.55%, the thistles that would remain to compete with the following year's crop would be only 0.9 to 1.2 shoots per 16 square feet; even less, if a 90% kill were expected.

At high levels of infestation, spraying would pay a large return. The two-year increment in yield from spray, at an initial infestation of 38.2 shoots per 16 square feet, is 19.4 bushels per acre. With wheat at \$2.00 per bushel, the expected return would be \$38.40 per acre. The expected return at 20 and 2.84 thistle shoots per 16 square feet would be \$15.60 per acre and \$1.22 per acre, respectively. These are the amounts the operator could afford to pay for a spray application at these

levels of infestation, ~~if the expected~~ reduction in thistle numbers were 66.55%. Even more could be afforded if a 90% kill were expected.

While yields are increased, the thistle infestation is decreased, and the increase in area and intensity of population is checked. The first application of spray reduced thistle numbers by an average of 89.89%. The second application reduced the numbers remaining after one spray application by 66.55%. Fifty percent of the half-plots treated were entirely free of thistles after two applications of spray. The use of 2,4-D seems very effective in controlling Canada thistle under the conditions in which the trials were made.

The increment in yield is affected to some extent by the adverse effect of the spray application on the crop. This effect has been reflected in an 8.3% loss from spray in the year of application. The hypothetical yield of 53.95 bushels per acre has been used throughout the analysis. If a smaller crop were expected, a lower bushel loss from spray would occur. A larger yield would give the opposite effect.

#### Limitations of Conclusions

The rate of spray has been taken as given at 3/4 pound of 2,4-D in 20 gallons of water per acre. Actual dates of spray were varied from year to year, in the trials, according to the time when Canada thistle was most susceptible (the pre-bud stage). The fields were apparently at a high level of fertility. No response was observed from nitrogen. All plots were fall plowed except in 1953, the initial year. In this year they were plowed in the spring before plotting. All plots were irrigated near July 1 each year, with a sprinkler system.

A yield level of 53,95 bushels per acre is assumed as a constant over the years concerned. In any given year this might more properly be regarded as a possible mean yield that might occur under a given combination of productive resources with similar weather conditions prevailing. The operator who expects a greater yield might also expect a greater bushel loss from non-selectivity of spray. The one whose yields would be less can expect a lower bushel loss than has been indicated.

The evidence indicates that any given level of infestation would decrease a small yield, say 20 bushels per acre, crop by the same number of bushels as would an equal number of thistles in a crop with a potential of 80 bushels per acre. For the operator, who is to make a decision, more information should be available for the yield he expects. The "mean" curve used in the analysis was developed from so few observations that its slope and height were not subjected to any statistical test. It was representation of the available indications.

Some information was available on the rate of increase from an infestation of 38.2 shoots per 16 square feet. But it was necessary to assume what rate might occur at low (1 to 5 shoots per 16 square feet) levels of infestation. Little attempt was made to account for lateral spread. A uniform infestation was generally assumed.

All plots, which were treated, originally had similar levels of thistle infestation (approximately 40 shoots per 16 square feet). No evidence was available as to whether spraying higher or lower levels of infestation would give the same percent reduction as at this level of infestation. It was necessary to assume that a 90% reduction would occur

from the initial spray application at any given level. Further, the trials were set up only on a one-year basis. So it was assumed that a 90% reduction would occur in any given first-year spraying.

It was necessary to assume that thistles which were sprayed in the first year would be reduced with the same effectiveness as those which had not been sprayed the previous year. Little evidence is available to support this assumption.

The analysis has not accounted for any added value of product from less foreign materials, particularly the seed of the noxious weed, Canada thistle. Neither does it account for any aesthetic values an operator may have for producing and showing fields free of weeds. Nor has it given substantial consideration to the possible spread of Canada thistle by seeding. Any and/or all of these would tend to encourage an operator to spray at lower levels of infestation than those found to be economically feasible in the preceding analysis.

It has been pointed out that Canada thistle, and, most likely, other weeds, do not develop in uniform infestations over an entire field. Some correction for non-uniformity can and should be made.

#### Implications of Findings

The discussion has been largely confined to a uniform infestation. Yet it is more likely that only certain areas of a field will be infested with Canada thistle. (See Appendix Figure 17 a.) Infestations may start along ditches (see Figure 17 c) or roadways and spread inward according to the normal growth pattern of Canada thistle or by disturbance and distribution of the rhizome system with tillage implements. If

infestations and seeding occur along ditch banks, viable seeds may be carried by irrigation water to various parts of the field. An occasional seed may be carried to the field by wind and establish a patch before it is noticed or controlled. Only extreme lack of patch control or heavy seeding by wind blown seed would completely infest a field with Canada thistle.

It is likely that the cost of application of 2,4-D per unit of area would be greater for small areas than for whole fields. It has been suggested that in fields where scattered patches exist, a device should be used for turning the spray off in uninfested areas to prevent damage to wheat where no increased yield can be expected from reduced competition.<sup>1/</sup> However, labor and machine costs would remain the same. The increment in yield would depend upon the density of the patch population. The economy of control would also be partially determined by the proximity of male (staminate) and female (pistillate) plants. If both male and female plant clones grow together, the situation is dangerous from the possibilities of seed infestations.

The "break-even" analysis, while developed under the assumption of uniform infestation, is also useful when non-uniformity and seeding is considered. The lack of uniformity would increase the per unit of area cost of control while the density within the patches would increase the increment in yield for the given area. If control were on a field basis, some estimate of the percent of the field area involved would need to be made, as well as the density within the infested areas.

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<sup>1/</sup> Myrick, op. cit.

For example, assumed that 10% of a 20 acre field is infested with an average of 20 shoots per 16 square feet. Assume also a linear relationship between thistle infestation and yield. Consistent with the previously used crop yield, the two infested acres would probably yield, then, an average of 42.6 bushels per acre with no "net effect" for spray accounted for, and 40.82 bushels per acre with a 4.2% "net-effect" accounted for.

At a cost of \$2.00 per acre for spraying, the total cost would be \$40.00. If thistle numbers are decreased by 90%, the next year's crop only competes with 1.8 shoots per 16 square feet. The yield would be expected to increase to 51.3 bushels per acre. In addition, by spraying, a loss of approximately 3.5 bushels per acre could be averted in the second-year crop without consideration for any lateral spread. The increment for spray on the two acres is 10.48 bushels per acre, giving a total of 20.96 bushels. With wheat priced at \$2.00 per bushel, the value of the spray application would be \$41.92, slightly greater than total cost, if interest on investment is ignored. Note that since only two acres were actually sprayed, the per acre cost of application was \$10.00 for those sprayed. If the spray has been used on the uninfested areas, the total loss to spray the first year would have been 82.42 bushels, considerably more than was gained in the two infested acres.

Some difficulty may be experienced in estimating, with any degree of accuracy, the amount of the field that is infested. Some measuring and experience would be valuable aids.

The economic effect of time between spraying and realization of returns has so far been ignored. Yet the major return comes in the second

crop after spraying. Some account can be made for it by discounting the return at any given level of infestation. For example, the return from spraying an infestation of 20 thistle shoots per 16 square feet was estimated to be \$15.60 per acre in the second year. If the opportunity cost of funds used in spraying is 10%, the value of the "year two" return, at the time of spray, can be found by dividing this \$15.60 by  $(1+.10)^2$ . This would be \$12.98 or the value of the return at the time of spray.

#### Suggestions for Further Research

The experimental plots, from which much of the data were obtained, were set up to study the physical aspects of Canada thistle eradication. Eradication, not maximum net enterprise income, was the assumed goal. The samples in farm fields were limited to avoid imposing upon the farmer. As a result, insufficient observations were made at any given yield level. Yields in various fields differed widely.

The conclusions which have been drawn are based on incomplete data and further physical research is necessary to give them more strength and reliability. The analytic model suggests a number of areas in which more economic research would be fruitful.

#### Reinfestation and "Net Effect" Data

The information on percent of reduction in thistles is the result of only one year's observation. If the plots were available, the trials should have been replicated over time in a series of at least three years to give more reliable estimates of the percent of reduction on the initial and remaining stands of thistle. Adequate numbers of plots should be prepared at the outset to permit study of the rate of reinfestation. This

could be done by leaving some of the plots unsprayed in the second and third years. The rate of reinfestation can be a large and deciding factor.

Supplementary work on the rate of lateral spread without spray should also be undertaken. Some study of the effects on spread of different tillage methods might also be attempted.

It has been held that seeding is not a particular problem in the spread of Canada thistle. Yet few data are available on this point. Some work needs to be done to determine the distances the seeds are carried by wind or water. A study of the viability of seeds could be beneficial. It seems quite likely, from the way Canada thistles tends to spread along water ways, where both male and female plants grow in close proximity, that this method of spread is more of a problem than has been previously expected.

The effect of spray on wheat (8.3% loss) under weed-free conditions was drawn from the best information available for the conditions and factors prevailing at the Experiment Station. Yet more experimental evidence is needed on this point. No trials were available for the years of 1953-55. Therefore, no figures were available on the loss in wheat at the time spray was used in these experimental plots during these years. Plots to study the effect of spray on weed-free wheat could be incorporated into the experiment. They should be studied several years since wheat may be in different stages of growth when Canada thistle is in the pre-bud stage.

Plots need to be large if no means are used to check border infestations. Border trenching might be used as a prevention measure. Trenches could be filled in the fall prior to plowing. Metal dividers are possible

but would seriously hamper normal field operations. Soil sterilants might also be used for the purpose. The risk of carrying rhizomes from one plot to another with tillage implements is always a possibility unless plots are worked separately.

#### Competition Reduction Data

Results from foregoing analysis depend, to a large extent, upon the amounts of loss experienced at increasing rates of infestation. Enough observations should be made to give more reliable estimates, particularly in critical levels of infestation, of the amount of loss to be expected from thistle competition. If a sufficient number of observations cannot be made under field conditions, some attempt should be made to establish a known number of thistles in previously weed-free plots. Viable parts of rhizomes could be sown in these weed-free plots. The number of rhizomes per plot could be varied to study a variety of infestation levels.

#### Further Economic Research Suggested

As mentioned at the outset, the lack of economic literature in the field of weed control seems to indicate that much work remains to be done. The preceding empirical analysis was done with only one of a number of selective weed control chemicals applied at a given rate, at a given time, on a particular weed in a particular crop. The use of 2,4-D and related compounds could be studied when used with any number of different annual crops, including horticultural crops. Also, a set of relatively simpler problems concerns the control of annual weeds in these crops.

The use of 2,4-D and related compounds could be fruitfully studied when used to control weeds in perennial crops such as alfalfa or pasture

grasses. They might also be studied when used in conjunction with crop rotations and fallow operations. Included in the experiment, from which the spring wheat data were taken, were a number of plots (see Figure 11) in which trials on controlling Canada thistle with rotations and perennial crops were attempted. These and also similar data that may be found elsewhere could be developed for economic conclusions by the methodology we have used.

Studying the timing and rates of spray for maximum resistance of grains or other crops to 2,4-D could be fruitful. While it is desirable to get maximum control of weeds it may contribute more to net income to spray them with lower rates and at the stage of growth of the crop when it is most resistant to damage from spray. This might result in less reduction of weeds per unit of area for the given spray application but would also reduce the damage to the crop from spray. For example, it might pay to spray two or more years at the nearly or totally resistant stage of crop growth, if such stage exists, rather than spray once at a rate and a date when weed numbers are reduced at a maximum rate but the crop is subject to greater injury. It may be that such flexibility may not exist for a given crop-weed situation but for those where it does it could be a fruitful area of research.

Selective chemicals, such as 2,4-D constitute only one of several methods used for controlling weeds. Such methods as fallow, cultivation, and/or crop rotations used for controlling either annual or perennial weeds in either annual or perennial crops should be subjected to economic analysis to determine their advantage. The comparative economy of different control measures could thus be established.

Different control measures should, perhaps, be tried under various climatic conditions and cropping systems to determine what effect they may have on the effectiveness of various control measures.

Some attempt should be made to determine land values under weedy conditions. Information is also needed on the price reductions caused by noxious weed seeds in grain -- especially seed grains.

"Break-even" Analysis in Plant Disease, Insect, and Other Weed Control

Some diseases, insects, and weeds spread with such rapidity or unpredictability that cost of eradication is best regarded a fixed insurance cost. Others spread at a more predictable rate. For those which can be safely "lived with" in small numbers, the foregoing analytic model could be adapted to a study of the economic consequences of their control.

A P P E N D I X

APPENDIX

INFESTATIONS AND YIELDS

Figure 17 is included to give visual comprehension of the general problem of Canada thistle control. Part a shows a typical infestation of Canada thistle in a wheat field. The picture was taken just prior to harvesting time when the thistles were nearing maturity. The darker colored patches are mostly male plants (see page 7) and the lighter colored ones are mostly female. Patches of different size and intensity of infestation are also distinguishable.

Part c shows part of the experimental plots from which much of the data were taken. The plots which were treated with 2,4-D are free of any visual infestation. All plots had nearly equal infestations in 1953. But after three successive years of 2,4-D treatment, the thistle-free plots yielded a mean of 50.2 bushels per acre, compared with only 28.2 bushels per acre for those not treated (see Table IV). The infestations, by count, were reduced to near zero in treated plots. In the untreated plots, the infestations had increased by 68%.

Part b shows an infestation of Canada thistle beginning along a ditch at the edge of a wheat field. The light, medium and heavy infestations of part b would produce, respectively, yields similar to those of the 3, 20, and 55 shoots per 16 square feet shown in part d. These sheaves shown in part d were actually harvested from single 16 square foot plots (at these levels of infestation) in the field shown in part a. The yield at 0, 3, 20, 35, and 55 shoots per 16 square feet was approximately 37, 33, 26, 20, and 14 bushels per acre, respectively.



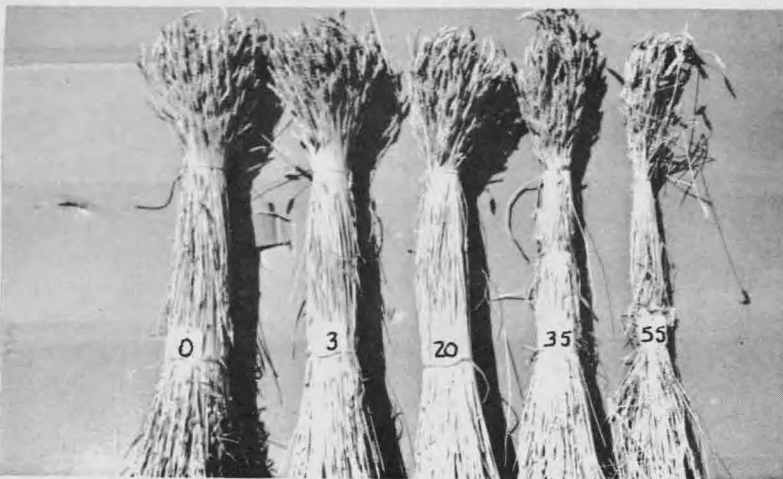
a



b



c



d

Figure 17. Irrigated spring wheat yields at various levels of Canada thistle infestation.

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