PERSISTENCE OF PICLORAM AND ITS EFFECTIVENESS FOR THE CONTROL OF CANADA THISTLE IN CEREALS

By

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ABSTRACT

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The movement and persistence of 4-amino-3,5,6-trichloropicolinic acid (picloram) in an Osborne clay soil and the effectiveness of picloram for Canada thistle (Cirsium arvense (L.) Scop.) control in wheat (Triticum aestivum L., cv. Manitou), barley (Hordeum vulgare L., cv. Conquest) and oats (Avena sativa L., cv. Harmon) were determined over a four year period.

Picloram concentrations were determined using sunflowers (Helianthus annuus L. var. Peredovik) and soybeans (Glycine max (L.) Merr. var. Altona) as bioassay plants. Application rates ranged from .5 to 10 oz/A with half of each plot receiving a repeat application the second year.

Movement and dissipation of picloram were negligible under low soil moisture conditions. Under high rainfall conditions picloram was leached into the 12-24 inch depth. A greater percent of the picloram was leached at the higher application rates. The potassium salt of picloram was more readily leached than the triisopropanolamine salt. Most of the picloram remained in the surface 6 inches, with only 14% of the 2 oz/A potassium salt and 8% of the 10 oz/A triisopropanolamine salt below the 6 inch depth.

Dissipation increased with temperature (days over 80F) and decreased with increasing depth in the soil profile. No accumulation was noted following two applications of picloram at 1 oz/A. However, on plots receiving two applications of 5 oz/A, 39% of the activity remained after

23.5 months.

Under low soil moisture conditions Canada thistle control was satisfactory only at 5 and 10 oz/A picloram. Under high rainfall conditions of 1968 thistle regrowth was stunted, chlorotic and deformed on plots treated with picloram at 2.5 oz/A or more applied in 1967 and at 1 oz/A or more applied in 1967 and 1968. The number of Canada thistle shoots doubled from 1967 to 1969 on the check and on the plots treated with (2,4-dichlorophenoxy)acetic acid (2,4-D) at 16 oz/A, and picloram at .5 and 1 oz/A, and decreased in 1970 on all plots except those with a low thistle density. Two applications of picloram at 2.5 oz/A applied a year apart maintained satisfactory control for three years. Canada thistle density increased at high fertility levels.

Crop injury was greater at low fertility levels. In 1969 crop injury was noted only on plots receiving 5 and 10 oz/A of picloram. Wheat yields on the 2.5 oz/A picloram treatments were always as great as on the check. In 1970 wheat yields on the 5 and 10 oz/A picloram treatments were significantly greater than on all other plots. Picloram reduced the length of the peduncle of wheat and many spikes remained in the flag leaf sheath.

On all picloram treated plots the percent protein in wheat increased, and the kernel size decreased in 1967 and increased in 1968 and 1969. Germination of kernels from treated plants was not affected.

Root sections of seven Canada thistle ecotypes were grown under 8-, 12-, 14- and 16-hr photoperiods. At the 14-hr photoperiod five ecotypes flowered, three were temperature dependent. Shoot and root development and plant height varied with ecotype. Both the root-to-shoot ratios and the number of shoot buds formed on the roots were inversely related to

temperature and length of photoperiod.

Herbicides tested for their effects on Canada thistle ecotypes were 2,4-D, picloram, and 3,6-dichloro-o-anisic acid (dicamba). Control of top growth increased with increasing temperature. Similarly, root contol was maximum at 80F, at which temperature there were few fleshy roots. Picloram, unlike 2,4-D and dicamba, caused little leaf damage, but completely destroyed the root system.

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INTRODUCTION

The competitive ability and persistence of a perennial weed is largely due to its ability to produce viable buds from its underground perennial root or rhizome system. Such a weed even if its top growth is destroyed repeatedly may still recover. Consequently, any control method or material, to be wholly successful, must kill virtually all of the plant.

After twenty-five years of selective herbicide use in Western Canada, hard-to-kill perennial weeds such as Canada thistle (Cirsium arvense (L.) Scop.) have become an increasingly dominant part of the weed problem. Their resistance to common herbicides, their hardiness and competitive ability under adverse conditions, and their ability to regenerate from a perennial root system make them a serious problem. A need exists for a more satisfactory selective herbicide for their control while allowing normal, or at least partial cropping to continue.

In the study described here, the objectives were to evaluate the factors influencing the effectiveness of 4-amino-3,5,6-trichloropicolinic acid (picloram) for Canada thistle control in cereals, and to determine its persistence under Southern Manitoba conditions.

LITERATURE REVIEW

Canada Thistle

Distribution. One or more varieties of Canada thistle can be found throughout the northern half of the United States and the southern part of most of the Canadian provinces (20). It is more common than any other weed in Montana, Idaho, Oregon, and Washington and it is reported to cause heavier losses than any other perennial weed (45). On the basis of calculations from a survey made by Alex (4), Manitoba, Saskatchewan, and Alberta are estimated to have 22 million acres of cultivated land infested with Canada thistle. Friesen and Shebeski (26) reported 11 of the 142 Manitoba grain fields sampled contained 10 or more plants per square yard.

Canada thistle is well adapted to a wide range of conditions but grows best in deep, productive, well-aerated soils and where temperatures are moderate and rainfall is 16 to 30 inches (8, 48).

Infestations are found not only in cultivated fields but also in pastures, on rangeland, along roadsides, in lawns and gardens, and in new areas, as it spreads each year (45).

Growth habit and morphology. Canada thistle is distinguished from other Cirsium thistles by its horizontal, branching, perennial roots, its erect stems branching towards the top, and its characteristic of growing in circular patches, with each new patch usually consisting of only one clone. The stems grow erect from 24 to 48 inches, arising from numerous buds on the horizontal roots. Stems of different clones vary from ribbed to smooth, often with a row of spines below the leaves. The leaves are usually dark green, deeply lobed, and ruffled on the margin with spines around the margin and at the tip of the lobes. Leaves occasionally are found to be smooth on the margins with no spines or very short spines.

Leaf surfaces are glabrous to hairy. Flowers are borne at the apex of stems. These stems are terminal or arise from leaf axils and branch several times. The flowers are mostly purple or blue with various shades (46).

Newly germinated Canada thistle seedlings require considerable light and usually become established on newly disturbed areas where competition is limited during the seedling stage. Once established Canada thistle is very competitive. The most rapid shoot growth is at a mean temperature of 61 to 65F (46).

Canada thistle is a long-day plant, requiring more than a 12-hr photoperiod to induce flowering. It is normally dioecious but florets on staminate plants are occasionally perfect. Flowers are mainly insect pollinated. The seeds mature quickly and are capable of germinating 8 to 10 days after the flowers open. Seed size varies considerably among different ecotypes (46).

Reproduction. Canada thistle propagates mainly by roots. However, because of its copious production of seeds attached to the pappus it is also spread great distances by wind currents.

Canada thistle has an extensive system of fibrous and branding horizontal roots. These roots continue to grow each season and contain an abundance of stored food that contributes to the perennial life of the plant. These roots repeatedly initiate new shoots. When roots are cut or broken into pieces, each piece is capable of developing new plants and establishing a new patch. Single newly established plants may spread over a circular area 20 feet in diameter in one year (45).

Susceptibility to different herbicides. The selective herbicides most commonly used are not translocated downward in sufficient quantities

to kill the underground meristematic regions. Seed production was prevented by (2,4-dichlorophenoxy)acetic acid (2,4-D), [(4-chloro-o-tolyl) oxy] acetic acid (MCPA), 4-(2,4-dichlorophenoxy)butyric acid (2,4-DB), and 3,6-dichloro-o-anisic acid (dicamba) and repeat treatments resulted in moderate control (25, 45, 46). Nitrogen fertilizer and a competitive crop in combination with 2,4-D gave increased control (46).

Canada thistle varieties and ecotypes showed a differential response to several herbicides (14, 28, 47, 77, 80). Marked differences in response of Canada thistle plants to 2,4-D have been reported. Survival after six treatments of 1.5 pounds per acre varied from 42 to 73 percent among the 10 ecotypes. Susceptibility was generally greater in the bud than bloom stage, however, the reverse was true for two of the ecotypes (44).

Stomatal number and area, quantity of ether soluble leaf cuticle waxes, and relative leaf weight varied significantly among Canada thistle ecotypes but there was no particular relationship of these factors to the varied response of the plants to 2,4-D (47). Light quality changed the tolerance limits of some ecotypes to 2,4-D (25).

Hodgson (44) found that Canada thistle survival after three annual 3-amino-s-triazole (amitrole) treatments at 4 pounds per acre varied from 14 to 71 percent among the 10 ecotypes. Smith _et al_. (80) observed that metabolites of amitrole appeared more quickly in the resistant ecotypes and that the presence of these metabolites could be influenced by light and temperature.

Epinasty, chlorosis, and necrosis developed more rapidly in the shoot of _C. arvense_ var. _mite_ than _C. arvense_ var. _horridum_ plants treated with 2,4-DB, 2,4-D, amitrole, dicamba, and picloram. Var. _horridum_ was

more resistant to 2,4-DB and dicamba than var. mite. Saidak (77) suggests there may be a varietal difference in the growth rate or distribution of the roots, or both.

Chemical Properties of Picloram

In its purified physical state 4-amino-3,5,6-trichloropicolinic acid (picloram) is a white powder with a slight chlorine-like odor. The molecular formula is $C_6H_3Cl_3N_2O_2$ with molecular weight of 241.5. It decomposes before melting at a temperature of approximately 215C and has a TOC flash point of 35C. Solubility in acetone, ethanol, and water is 1.98, 1.05, .043 g/100 ml at 25C, respectively. Oil solubility is low, only .001 g/100 ml in kerosene. It is commercially formulated as the water soluble triisopropanolamine salt in combination with 2,4-D or as a potassium salt, which decreases the solubility in acetone but increases the water solubility to 40g/100 ml at 25C (43).

Toxicology of Picloram

Picloram is low in toxicity to humans, livestock, or wild life, including aquatic organisms. Picloram is relatively innocuous with no alarming pharmacological or toxicological properties and no primary metabolic breakdown products accumulate in the tissues of these organisms (22, 65, 67).

Picloram dosages as great as 1000 ppm generally had little effect on soil microorganisms (7, 32). Tu and Bollen (81) concluded that the overall effects of picloram on ammonification, nitrification, sulfur oxidation, and organic decomposition was of little significance. Although picloram at 1 and 10 ppm had a stimulating influence on microbial numbers and activity it was insufficient to be considered important to soil fertility.

Evidence indicates that treatment of rangeland or fields of small

grains with effective dosages of picloram herbicides does not produce toxic residues in animal feeds, nor in foods to be consumed by humans (10, 11, 12, 61, 67).

Fate of Picloram in Plants

Penetration and translocation. Root and foliar uptake are both important routes of entry for accumulation of phytoxic amounts of picloram (13).

Hurtt and Foy (52) found that penetration in beans increased with time up to 48 hours. Bovey et al. (13) found that a 24 hour period was required to move lethal amounts of picloram into stem and root tissue of huisache (Acacia farnesiana (L.) Willd) after a foliar treatment. The bulk of the picloram was found in or on the leaves, and persisted for long periods (30 days) with little or no apparent breakdown. The concentration in roots from soil applications were similar to foliar treatments.

Moisture stress had no apparent effect on absorption of picloram, 2,4-D, or (2,4,5-trichlorophenoxy)acetic acid (2,4,5-T) by bean plants (71, 75). Moderate stress reduced the amount of 2,4-D translocated but had no significant effect on translocation of picloram. In plants stressed to visible wilting, translocation of 2,4-D and 2,4,5-T were greatly reduced, and the concentration of picloram in stem and apex was reduced to 57 percent of the control plants (9).

Penetration and translocation of picloram and 2,4-D in aspen (Populus tremuloidies Michx.) and balsam poplar (Populus balsamifera L.) increased with an increase in temperature from 10 to 40.5C. Penetration occurred more rapidly from the abaxial than from the adaxial surface (79). In field bindweed (Convolvulus arvensis L.) absorption of picloram was greater than 2,4-D and was greatest in adult plants; translocation was

greatest in seedlings, the roots of which had considerably more chemical (1).

Movement of 2,4-D and picloram has been shown to occur with the translocates in plants, acropetally and basipetally (3). Foy et al. (24) showed that foliarly applied picloram was readily transported via the phloem, excreted from roots of treated plants, and reabsorbed by untreated plants growing in the same medium. Root applied picloram was readily distributed to the shoot via transpiration stream and redistributed. There was a preferential accumulation in the areas of greatest metabolic activity.

Picloram is phytotoxic to the transport system in plants, and at high concentrations interferes with the movement of photosynthates (64). The presence of leaves is important in the distribution of picloram and 2,4-D. In field bindweed translocation was toward the young leaves and growing tips and away from the basal leaves (3). Bovey et al. (13) showed that more picloram was translocated to the roots in the presence of leaves in huisache than when leaves were absent. It appears that removal of leaves does alter the direction of distribution of the foliarly applied herbicides.

Anatomical and morphological effects. Picloram acts as a potent auxin in a variety of test systems when used at low concentrations and bears marked similarities to that of 2,4-D and 2,4,5-T (18, 19, 49). Eisinger et al. (18) found that quantitatively picloram, 2,4-D and 2,4,5-T caused similar stimulation of polarized cell elongation in stem sections. Picloram, 2,4-D, and indoleacetic acid (IAA) all support growth of tissue explants in culture, inhibit root growth, induce cell wall loosening, produce stem curvature, promote loss of chlorophyll, induce abscission responses, and other formative effects. The ability of picloram to markedly increase the growth of intact shoot cuttings is not shared by either 2,4-D

or IAA (18, 49). Increase in epicotyl length was accompanied by decreased root initiation in cuttings (19).

Picloram like other auxins was found to be inhibitory to root growth between 10^{-10} M and 10^{-5} M (53). Inhibition appeared to be greater when cell division was taking place along with elongation than when elongation occurred alone.

In treated bean plants Fisher et al. (21) found the vascular cambium was no longer in radial files and roots were initiated from the cambial region of the stem. Epidermal and hypodermal cells enlarged while cortical cells remained normal. The proliferation of the cambium and enlargement of epidermal and hypodermal cells created large air spaces in the cortex around areas of meristematic activity. The root initial continued to develop, pushed phloem cells and fibers aside, ruptured the cortex and epidermis, and caused visible fissures. At higher rates (7.2 to 72 ug) root initials were initiated in the leaves. The abaxial epidermal cells enlarged, creating large air spaces visible as chlorotic regions. At less than .72 ug per plant, apical growth was only retarded and flowering delayed. Wax et al. (85) showed that picloram also increased branching.

Lee et al.(63) found that, unlike 2,4-D which caused considerable damage to the leaves of Canada thistle but had little influence on cellular structures in the roots, picloram (.25 pound per acre) caused no damage to any cell structures in the leaves but the roots displayed a partial disorganization of cortical cells seven days after treatment, and this disorganization was more pronounced after 14 days. After 25 days, Kreps and Alley (60) found the cortex, phloem, and cambium were completely destroyed while the xylem and periderm remained intact.

Physiological effects. Young et al. (86) determined that picloram

(3 pounds per acre) increased the amino acid content in field bindweed, susceptible, while in kochia (Kochia scoparia Schrad.), resistant, there was no increase. In both, the carbohydrate content was increased. The chlorophyll content was higher in the treated bindweed and untreated kochia than in the untreated bindweed and treated kochia. This is not congruent with Eisinger's results (18).

Malhotra (66) found that picloram decreased DNA, RNA, and protein in resistant plants such as barley whereas the reverse was true of susceptible plants such as soybeans. It was suggested that picloram may promote nucleic acid synthesis in both the resistant and susceptible species, however, the presence of higher levels of native bound nucleases in the resistant species prevents the accumulation of nucleic acids.

Combination with other herbicides. Picloram in combination with a phenoxy herbicide such as 2,4-D or 2,4,5-T is effective for a wider spectrum of weeds. In combinations, lower rates of picloram are used, thus the persistence of residues is reduced in soil. Alley (6) found that in combination with 2,4-D only half as much picloram was required for adequate Canada thistle control. Krawiec and Morre (59) found that at least 25 percent of the picloram herbicide at a given treatment rate was replaceable by 2,4-D or 2,4,5-T without a significant decline in overall herbicide effectiveness (apparent synergism).

When picloram and 2,4,5-T were combined, the uptake and translocation of picloram was increased and translocation of 2,4,5-T was decreased (17). Picloram increased the translocation of 2,4-D, but the reverse was not true (2).

A possible limitation to the combination is the addition of 2,4-D to picloram increases wheat injury at the two to four leaf stage (74).

Fate and Persistence of Picloram in Soil

Volatilization. Gentner (31) showed that the vapors of picloram formulated as the potassium salt were herbicidally active in a closed system. Vapors from the .25, .5, 1, and 2 pounds per acre treatments reduced growth of Pinto beans by 66, 87, 92, and 100 percent, respectively.

Under field conditions volatilization is normally of little significance due to a vapor pressure of 6.66×10^{-7} mm Hg at 35C and rapid soil sorption (43, 70).

Photodecomposition. Photodecomposition may be responsible for the loss of picloram if it remains on the soil surface for extended periods of sunny weather. Merkle et al. (70) found that 60 percent of 1 mg of picloram in petri dishes was degraded by ultraviolet light in 48 hours, 35 percent was degraded by sunlight. Degradation from a soil surface was considerably slower, 15 percent by a week of November sunlight.

Hall et al. (38) found that two chlorine ions were liberated for each molecule of picloram degraded, acids were formed, the pyridine nucleus was destroyed, and at least five products were formed.

Chemical degradation. Hance (42) found that the rate of breakdown of picloram was dependent on the quantity of soil present but not on the extent of adsorption. At high ratios of soil to herbicide, non-biological chemical degradation could possibly be a significant pathway by which picloram is lost from soil. The reaction occurred only at specific sites in the soil, therefore, the rate of breakdown varied with the soil type and the amount of dispersion of the herbicide.

Plant metabolism. Merkle et al. (69) determined picloram decomposition in soil containing living plant roots by measuring carbon ^{14}C dioxide evolution. A zero-order rate of picloram decomposition was approximated

up to 15 days followed by a large increase and a leveling off. The relative decomposition rates were 1:2:26 plant:bare soil:soil with plant. Picloram was the only herbicide extract detectable, 3 percent of which was combined as an amide with terminal amino groups of insoluble protein. Redemann et al. (76) found the distribution of metabolites in wheat grain and straw to be 4-amino-3,5,6-trichloropicolinic acid, 83 percent; oxalic acid, 8 percent; 4-amino-2,3,5-trichloropyridine, 4 percent; and 4-amino-3,5-dichloro-6-hydroxypicolinic acid, 5 percent.

The biochemical transformations, whether by plants or by microorganisms, yielded compounds much more readily disposed of by living systems than was the herbicide itself. The first step was the rate determining step. Thus, the only compound one finds in major quantities is the herbicide itself (76).

Microbial degradation. Picloram is degraded by a variety of microorganisms (7, 69, 72, 87). Youngson et al. (87) found that sterilization almost completely eliminated decomposition and the rate of decomposition varied with the nature of the microbial population of the soil. Picloram decomposition occurred along with the breakdown of organic matter and was not a preferred energy source, thus for 1 lb herbicide degraded 10,000 to 100,000 lbs of soil organic matter were decomposed. There was no lag period in the decomposition of picloram. Grover (34) had suggested there was a lag period prior to the degradation and that the duration of the lag period increased as the concentration of picloram in the soil was increased. The rate of degradation tended to be independent of the concentration of herbicide; the percent decomposed decreased as the concentration increased (87).

Adsorption. Hamaker et al. (39) found that sorption of picloram was primarily caused by organic matter and hydrated metal oxides, with clays

playing a minor role. Sorption increased significantly with time for organic soils but not for hydrated metal oxides. The slow equilibrium for organic soils suggested initial surface sorption followed by slow diffusion of the unionized acid molecules into the interior of a lipid-like phase (39). It has been suggested that adsorption was greatest at a low pH (35, 39) and was negligible to the soil colloid phase under alkaline conditions (36). The bioactivity of picloram decreased as the soil-moisture content increased due to its effect on the concentration of picloram in the soil-water phase.

Leaching. Leaching is greatest in light textured soil low in organic matter. Scifres et al. (78) found that the amount of detectable picloram in a clay loam soil was the same in the upper 2 feet of the profile whether 1 or 2 pounds per acre were applied. As the application rate increased, the total amount of detectable picloram residue in the subsoil profile increased. Merkle et al. (70) suggested leaching to be an important means of dissipating the herbicide in light soils. But in the subsoil the longevity of picloram was increased due to reduced organic matter content, lower microbial activity, and lower temperature (78).

Problems of picloram persistence in soil. Degradation of picloram was highly correlated with percent soil organic matter, moisture as a percent of the water holding capacity and temperature (87). At 55.8 percent of the water holding capacity decomposition was maximum, at 18.1 percent, decomposition decreased over 90 percent. Ten to 25-fold increases in rate of decomposition, accompanied by an increase in efficiency of decomposition, were obtained by increasing the temperature from 35 to 94F (87). Disappearance of picloram was also related to the amount of chemical dispersion, temperature (days over 90F), annual precipitation, soil

type, rate of application, and nature of the microbial population (33, 41, 72). These factors are for the majority of cases, unpredictable and variable from location to location and season to season.

The persistence of picloram in the soil, although a vital and necessary integral part of its herbicidal activity, will, together with the tolerance of the crop to be planted, determine the interval between herbicidal treatment and successful growth of a normal crop (33).

Effects of Picloram on Canada thistle

Various rates and formulations of picloram have provided good control of Canada thistle (16, 23, 28, 46, 68) for varying lengths of time, under certain conditions and situations. Rates of 12 ounces per acre reduced the Canada thistle stand on roadsides by 80 to 100 percent (23). In cultivated fields 2 years after application, 8 ounces per acre gave complete eradication (68); 4 ounces per acre in the bud stage gave 70 to 90 percent control (83); 2 ounces per acre on a wheat crop provided partial control while 1 year after a fall application, 4 ounces per acre provided excellent control (56, 57).

Friesen (28) noted slight regrowth of Canada thistle where rates were below 4 ounces per acre. He pointed out that the "entire-leaved strain" of Canada thistle was distinctly more tolerant to picloram and showed more vigorous recovery than did the common "spiny" form.

Effects of Picloram on Cereals

Nalewaja (74) found that wheat was most susceptible to picloram at the late tiller stage and independent of rate of application between .5 and 2 ounces per acre. Wheat injury was manifested by lower kernel yield, greater protein content in the kernels, and reduction in plant height. The reduction in the stem length was greatest in the peduncle

and resulted in some spikes partially remaining in the flag leaf sheath. The flag leaf sheath was not reduced in length. The effect of picloram on kernel size was variable but did not influence germination of kernels from treated plants. At higher rates others (73, 82, 84) have reported stem curvature, onion leafing, head deformities, and a delay in maturity. The straw shortening response was evident at much lower rates than was yield reduction (27, 55, 73, 82, 84) and occurred less under drought conditions (30, 54). Oats and barley showed similar injury symptoms but were much more tolerant to picloram than was wheat (55, 73, 82, 84).

SECTION 1

Movement and Persistence of Picloram in Soil[1]

J. H. Hunter and E. H. Stobbe[2]

Abstract. The movement and persistence of 4-amino-3,5,6-trichloropicolinic acid (picloram) in an Osborne clay soil was determined over a 4 year period. Picloram concentrations were determined using sunflowers (Helianthus annuus L. var. Peredovik) and soybeans (Glycine max (L.) Merr. var. Altona) as bioassay plants. Application rates ranged from .5 to 10 oz/A. Movement and dissipation of picloram were negligible under low soil moisture conditions. Picloram was not readily leached but under high rainfall conditions picloram was leached into the 12-24 inch depth. A greater percent of the picloram was leached at the higher application rates. The potassium salt of picloram was more readily leached than the triisopropanolamine salt. Most of the picloram remained in the surface 6 inches, with only 14% of the 2 oz/A potassium salt and 8% of the 10 oz/A triisopropanolamine salt below the 6 inch depth. Dissipation increased with temperature (days over 80F) and decreased with increasing depth in the soil profile. Two applications of picloram at 1 oz/A applied in two successive years showed no accumulation, but accumulation occurred from two applications of 5 oz/A, 39% of the activity remained after 23.5 months.

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INTRODUCTION

Many hard-to-kill annual and perennial weeds can be controlled by 4-amino-3,5,6-trichloropicolinic acid (picloram) (1, 3, 6, 7). The susceptibility of certain crops to extremely small quantities of picloram (9, 10) and the persistence of this herbicide in soil (5, 8) are important considerations in the prolonged control of perennial species on agricultural land.

This study was conducted to determine the movement and persistence of picloram after several applications to a heavy clay soil under Manitoba conditions.

MATERIALS AND METHODS

Field experiments were conducted in 1967 - 1970 in Southern Manitoba on an Osborne clay soil, (Table 1) a reasonably well drained, dark-colored, heavy textured lake-bed soil.

Plots were seeded to wheat (Triticum aestivum L., cv. Manitou), and several rows of sensitive indicator plants, sunflowers (Helianthus annuus L. var. Peredovik) and soybeans (Glycine max (L.) Merr. var. Altona). Spring tillage consisted of a one-way disking and harrowing, fall tillage was two applications of a one-way disker. In 1969 each plot was tilled to a depth of 5 inches with a deep-tiller.

The experimental design was a split plot with four replications of eight treatments. Three formulations of picloram were used, triisopropanolamine salt (202) with 2 oz of picloram and 32 oz of (2,4-dichlorophenoxy) acetic acid (2,4-D) per imperial gal, triisopropanolamine salt (212) with 1 lb. of picloram and 2 lb. of 2,4-D per American gal, and potassium salt (22K) with 2.4 lb. of picloram per imperial gal. The treatments were check, 2,4-D 16 oz/A, and picloram (202) .5, 1 oz/A, (22K) 2 oz/A and (212) 2.5, 5, 10 oz/A. The chemicals were applied in 5.4 gal of water/A. The plots were

Table 1. Physical and chemical characteristics of the Osborne clay soil at three depths.

Depth (inches)	Sand (%)	Silt (%)	Clay (%)	pH	Organic matter (%)	Cation exchange capacity meq/100 g	Moisture-holding capacity (%)
0-6	3.8	24.2	72.0	6.8	8.8	58.0	44.1
6-12	2.7	22.4	74.9	7.2	3.8	55.5	42.2
12-24	3.2	27.1	69.7	7.4	2.6	53.6	40.3

separated by an untreated area. The plots 14 ft by 21 ft were sprayed June 15, 1967 when the wheat was in the 2-3 leaf stage. On June 19, 1968 a repeat application was made to half of each plot. In 1969 and 1970 [(4-chloro-o-tolyl)oxy] acetic acid (MCPA) at 4 oz/A was applied for wild mustard control.

Soil was collected from the 0-6, 6-12 and 12-24 inch depths from all plots including the checks. The 0-6 inch sample was collected at 0-3 and 3-6 inch depths prior to the 1967 fall tillage. For each depth the soil from the four replicates was thoroughly mixed to give a uniform sample, and sealed in heavy plastic bags. Samples were dried for 24 hours at 80C, ground, sealed in heavy plastic bags and kept in cool storage until required for bioassaying.

Soil samples weighing 150 grams were placed in 7 oz plastic cups. Eight sunflower or soybean seeds, pre-soaked in distilled water for 6 hours, were planted in each cup and the soil moisture content was brought to field capacity. Each treatment was replicated eight times. Cups were placed in a growth cabinet maintained at 25C, a 16-hr day length and 1800 ft-c. The soil was watered daily to field capacity. Ten days after planting, plants were thinned to five per cup.

Standards of known concentration for each sampling date and soil depth were prepared in the same way as described above, using untreated soil, sufficient picloram to give concentrations ranging from 2-300 ppb, and enough water to wet the soil to field capacity. The sensitivity of the bioassay ranged from 2-300 ppb, but was greater at low rather than high concentrations. Field samples with expected high herbicide concentrations were diluted with untreated soil from the corresponding depth so that available picloram was within the range of the standards.

Standards were prepared 2 weeks prior to the planting date to allow

the herbicide to equilibrate with the soil. The standards and field samples were planted at the same time and grown under similar conditions.

Picloram concentration in the field samples was determined by visually comparing symptoms of the indicator plants with the standards 14, 21 and 28 days after planting. In the field, the residue was detected by visually comparing indicator plants in treated and check plots.

RESULTS AND DISCUSSION

The bioassay of soil samples taken 27 days after treatment indicated all of the picloram detected remained in the 0-3 inch depth. The 2,4-D treatment did not show phytotoxic effects on the bioassay plants, therefore the 2,4-D in the mixtures was not further considered. The relatively high total recovery of picloram (70 - 93%) detected by the bioassay and its distribution pattern (64 - 84% in the top 3 inches) suggests that there was little downward movement or dissipation of the herbicide in 1967 (Table 2). The precipitation for this period was unusually low, 4.04 inches (Table 3). Less picloram was recovered for the same period in a similar experiment on the same soil type receiving 6.6 inches rainfall. In June 72% and in October 18% of the 1 oz/A application remained in the 0-3 inch soil depth with no picloram detectable in the 3-6 inch depth, indicating dissipation.

Youngson *et al.* (11) showed that picloram decomposition decreased over 90 percent when the soil moisture decreased from 55.8 to 18.1 percent of field capacity. It is suggested that in this study the picloram applied in 1967 remained on or near the surface in dry soil, accounting for the limited decomposition.

The plots received 17.63 inches of rainfall between the June and August 1968 samplings, much of which was torrential in nature (.6 inches in 15 min, 4.95 inches in 2 hrs). It was mainly during this period that the detectable picloram in the 12-24 inch depth increased, for the 5 oz/A

Table 2. Percent recovery of picloram from soil, at successive depths and sampling dates, applied at six rates in 1967 (June 15).

Date sampled	Interval (months)	Depth (inches)	Formulation[a] and rate of picloram application (oz/A) 202 .5	202 1	22K 2	212 2.5	212 5	212 10
12/7/67	.9	0-3	96	96	100	96	96	96
		3-6	0	0	0	0	0	0
27/10/67	4.4	0-3	64	64	76	77	80	84
		3-6	6	8	8	10	8	8
		6-12	0	0	0	0	1	1
30/5/68	11.6	0-6	51	48	56	64	67	72
		6-12	0	6	13	6	6	7
		12-24	0	0	0	0	0	0
19/6/68	12.3	0-6	32	32	45	54	56	61
		6-12	0	6	13	5	6	8
		12-24	-	0	0	0	0	0
28/8/68	14.6	0-6	0	0	6	15	18	22
		6-12	0	0	10	3	5	10
		12-24	-	-	0	0	1	2
3/11/68	16.8	0-6			0	5	10	11
		6-12			3	0	3	10
		12-24			0	0	0	3
23/5/69	23.5	0-6			3	6	10	13
		6-12			3	0	3	8
		12-24			0	0	0	3
12/7/69	25.2	0-6			0	0	0	6
		6-12			0	0	0	3
		12-24			-	-	0	2
1/9/69	26.9	0-6					0	0
		6-12					0	0
		12-24					0	0
17/6/70	36.5	0-6					1	2
		6-12					0	0
1/9/70	39.1	0-6					0	0
		6-12					0	0

[a]For formulation see page 17.

Table 3. Rainfall and temperature for the interval between the dates the soil was sampled.

	Rainfall[a] (inches) and temperature (days over 80F)										
	1967		1968				1969			1970	
	12/7	27/10	30/5	19/6	29/8	3/11	23/5	12/7	1/9	17/6	1/9
Rainfall	1.07	2.97	5.38	1.89	17.63	3.98	3.39	4.47	3.80	13.19	5.33
Temperature	14	32	0	2	9	4	2	5	32	4	52

[a] Figures represent rainfall exclusively.

treatment (Table 2) it increased from 0 - 1% and for two applications of 5 oz/A (Table 4) it increased by 2%. These bioassay results indicate that under normal conditions the herbicide was not readily leached but under unusually abundant rapid rainfall it was leached into the 12-24 inch depth.

As the application rate increased, the percent of picloram detected in the 6-12 and 12-24 inch portions of the profile increased. The 22K formulation of picloram appeared to be more readily leached than the 202 or 212 formulations.

The greatest picloram activity detected below the 6 inch level was 14% for 2 oz/A of the 22K salt and 8% for 10 oz/A of the 212 salt (Table 4).

The 1969 and 1970 spring bioassay results indicate that during the winter season dissipation was extremely slow. The reduction in recoverable picloram in soil collected after spring tillage in May 1968 was probably due to a thorough mixing of the soil and adsorption to the incorporated straw.

Comparison of the percent of picloram recovered (Tables 2 and 4), and temperature (days over 80F) (Table 3) for each soil sample interval suggests that temperature is a major factor limiting dissipation. In 1969 at 5 oz/A the percent dissipation from May 23 to July 12 to September 1 was 9% and 22% with 5 and 32 days over 80F, respectively. These results are in agreement with Hamaker et al. (5) who found that the rate of herbicide loss was correlated with temperature (days over 90F).

The loss of picloram was generally most rapid immediately following application, and the rate of dissipation decreased with increasing depth in the soil profile (Table 2 and 4). Increased persistence of picloram in the subsoil may result from reduced organic matter content, lowered microbial activity and lower temperatures.

Table 4. Percent recovery of picloram from soil, at successive depths and sampling dates, applied at six rates in both 1967 (June 15) and 1968 (June 19).

Date sampled	Interval (months)	Depth (inches)	Formulation[a] and rate of picloram application (oz/A) 202 .5	202 1	22K 2	212 2.5	212 5	212 10
28/6/68	14.6	0-6	32	29	32	38	42	48
	2.3	6-12	0	8	12	5	6	6
		12-24	0	0	2	1	2	2
3/11/68	16.8	0-6	0	8	16	22	32	37
	4.5	6-12	0	0	8	5	5	6
		12-24	0	0	4	1	2	2
23/5/69	23.5	0-6		13	16	22	32	37
	11.2	6-12		0	8	5	5	6
		12-24		0	4	1	2	2
12/7/69	25.2	0-6		0	8	13	26	29
	12.9	6-12		0	4	3	3	5
		12-24		-	3	1	1	2
1/9/69	26.9	0-6			0	0	6	10
	14.6	6-12			0	0	1	2
		12-24			0	0	1	1
17/6/70	36.5	0-6				2	3	8
	24.2	6-12				0	1	2
		12-24				-	1	1
1/9/70	39.1	0-6				0	1	1
	26.8	6-12				0	0	0
		12-24				-	0	0

[a]For formulation see page 17.

Picloram applied June 15, 1967 at 1 oz/A retained 38% of its activity when sample 12.3 months later. The 1969 bioassay results indicated that with sufficient precipitation a 1 oz/A repeat application does not result in a residue build-up. However, accumulation of picloram from two applications of 5 oz/A could become a serious problem as 39% of the activity remained after 23.5 months. The percent of picloram recovered increased as the rate of application increased, indicating inactivation of greater percentages of small rather than large dosages during the same period. The quantity of picloram lost was greater from the large rather than the small dosages.

Picloram residues were not detectable in wheat straw bioassayed with tomato plants, however, Bjerke (2) has shown residues may be present in the straw. In this study at very low soil residue levels, the percent of picloram recovered from soil sampled after the winter months (23/5/69 and 17/6/70), increased in the 0-6 inch depth. This increase may mean that picloram is released from organic matter faster than it is degraded under low temperatures and would show symptoms in seedlings as sensitive as soybeans.

Field grown cereals generally showed greater picloram activity than did the greenhouse plants. Visual observation of field plots suggested that crop tolerance to picloram increased under optimum fertility. Friesen and Dew (4) showed that levels of soil moisture and air temperature which favored optimum growth increased picloram activity on tartary buckwheat. The increase in picloram activity on tartary buckwheat and the decrease in activity on cereals suggest that the selectivity of picloram is increased by optimum growing conditions.

By supplying optimum fertility for a competitive crop and using a split application a year apart to reduce the initial application rates,

the residue damage to cereal crops may be reduced.

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SECTION 2

PICLORAM FOR CANADA THISTLE CONTROL IN CEREALS[1]

J. H. Hunter and E. H. Stobbe[2]

Abstract. Field experiments were conducted from 1967 to 1970 with 4-amino-3,5,6-trichloropicolinic acid (picloram) for control of Canada thistle (Cirsium arvense (L.) Scop.) in wheat (Triticum aestivum L., cv. Manitou), barley (Hordeum vulgare L., cv. Conquest), and oats (Avena sativa L., cv. Harmon). Application rates ranged from .5 to 10 oz/A of picloram with half of each plot receiving a repeat application the second year. Under low soil moisture conditions Canada thistle control was satisfactory only at 5 and 10 oz/A of picloram. Under high rainfall conditions of 1968 regrowth was stunted, chlorotic, and deformed on plots treated with picloram at 2.5 oz/A or more applied in 1967 and at 1 oz/A or more applied in 1967 and 1968. The number of Canada thistle shoots doubled from 1967 to 1969 on the check and on the plots treated with (2,4-dichlorophenoxy)acetic acid (2,4-D) at 16 oz/A, and picloram at .5 and 1 oz/A, and decreased in 1970 on all plots except those with a low thistle density. Two applications of picloram at 2.5 oz/A applied a year apart maintained satisfactory Canada thistle control for three years. Canada thistle density increased at high fertility levels. Crop injury was greater at low fertility levels. In 1969 crop

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injury was noted only on plots receiving 5 and 10 oz/A of picloram. Wheat yields on the 2.5 oz/A picloram treatments were always as great as on the check. In 1970 wheat yields on the 5 and 10 oz/A picloram treatments were significantly greater than on all other plots. Picloram reduced the length of the peduncle of wheat and many spikes remained in the flag leaf sheath. On all picloram treated plots the percent protein in wheat increased, and the kernel size decreased in 1967 and increased in 1968 and 1969. Germination of kernels from treated plants was not affected.

INTRODUCTION

After twenty-five years of selective herbicide use in Western Canada, hard-to-kill perennial weeds such as Canada thistle (Cirsium arvense (L.) Scop.) have become an increasingly dominant part of the weed problem. Their resistance to common herbicides, their hardiness and competitive ability under adverse conditions, and their ability to regenerate from a perennial root system make them a serious problem. A need exists for a more satisfactory selective herbicide for their control while allowing normal, or at least partial cropping to continue.

In crop land 4-amino-3,5,6-trichloropicolinic acid (picloram) shows promise for controlling small infestations of Canada thistle (1, 4), however, certain cereal grains, notably wheat, are susceptible to small quantities of picloram (7).

This study was conducted to evaluate the effectiveness of picloram for Canada thistle control, and its effects on cereal crops.

MATERIALS AND METHODS

Field experiments were conducted in 1967-1970 in Southern Manitoba on an Osborne clay soil having a uniform Canada thistle infestation.

Experiment I was set up in a split plot design with four replications of eight treatments. Main plots were the treatments and subplots were a

single or double application. Wheat (Triticum aestivum L., cv. Manitou) was the cereal crop used in this experiment. Plot size was 14 ft by 21 ft. The initial (single) application (A) was made on June 15, 1967 when the wheat was in the 2-3 leaf stage. On June 19, 1968 a repeat application was made to half of each plot (B). Three formulations of picloram were used, triisopropanolamine salt (202) with 2 oz of picloram and 32 oz of (2,4-dichlorophenoxy)acetic acid (2,4-D) per imperial gal, triisopropanolamine salt (212) with 1 lb. of picloram and 2 lb. of 2,4-D per American gal, and potassium salt (22K) with 2.4 lb. of picloram per imperial gal. The treatments were check, 2,4-D 16 oz/A, and picloram (202) .5 and 1 oz/A, (22K) 2 oz/A and (212) 2.5, 5 and 10 oz/A. Main plots were separated by an untreated area. In the spring all plots were tilled once with a one-way disker and harrowed, in the fall all plots were worked twice with a one-way disker. In 1969 each plot was tilled to a depth of 5 inches with a deep tiller. In each of 1968 and 1969 the plots received a fertilizer application of 60 lb/A of nitrogen (N) and 16 lb/A of phosphate (P_2O_5).

In 1969 and 1970 all plots received 4 oz/A of [(4-chloro-o-tolyl)oxy] acetic acid (MCPA) for wild mustard control. Canada thistle populations were determined in triplicate square yard quadrants in the center of each plot in June, before treatment, and in August of 1967 and in June of 1968, 1969 and 1970. Yield was determined from the center 3 ft by 21 ft of each plot. Determinations were made of the milling and baking quality, 100 kernel weight, percent germination, and percent protein (micro-Kjeldahl nitrogen in wheat grain at 0% moisture x 5.7).

Experiment II. In 1968 a second experiment was initiated in which the main plots were seeded to wheat (Triticum aestivum L., cv. Manitou), barley (Hordeum vulgare L., cv. Conquest) and oats (Avena sativa L., cv. Harmon), and the subplots were the six treatments, check and picloram

212 at 1, 2, 4, 6, and 8 oz/A. The plots were replicated four times. The plots were reseeded in 1969 to wheat, barley and oats, and in 1970 to wheat. All plots received a yearly application of 16 lb/A of N and 16 lb/A of P_2O_5 fertilizer. MCPA at 4 oz/A was applied in 1969 and 1970 for wild mustard control. Yield was not determined.

In 1969 a second set of plots was established similar for the first two years to the ones described above, except this set of plots received a yearly application of 60 lb/A of N and 16 lb/A of P_2O_5 fertilizer. Yield was determined on the center 3 ft by 21 ft of each plot.

In experiment I and II Canada thistle control and crop damage were assessed visually (1 no effect, 9 complete kill). Crop injury was assessed on the basis of delay in maturity, reduction in crop height, lodging, deformities, and yield reduction.

RESULTS AND DISCUSSION

In 1967 the Canada thistle population on 2,4-D treated plots decreased relative to the check plots. Only picloram at 10 oz/A significantly reduced the Canada thistle population relative to the 2,4-D treatment (Table 1). The precipitation in 1967 was unusually low (2.94 inches June 1 to September 1), and the picloram remained on or near the soil surface (5). The Canada thistle foliage was killed but regrowth occurred with all treatments. At the higher rate of application, 5 and 10 oz/A, regrowth appeared chlorotic.

In 1968, picloram was moved by incorporation and leaching (5) into the root zone increasing the Canada thistle control on plots having a residue from 1967 and all plots retreated in 1968 (Table 1). Regrowth in 1968 was stunted, chlorotic and deformed with a treatment of 2.5 oz/A or more applied in 1967 or 1 oz/A or more applied in 1967 and 1968.

Control of Canada thistle with 2,4-D at 16 oz/A and picloram at .5

Table 1. Number of Canada thistle shoots per sq yd for four years with eight treatments applied in 1967 (A) and in 1967 and 1968 (B).

Treatment	Rate (oz/A)	Canada thistle per square yard						
		Before treatment	1967	1968		1969		1970
			A	A	B	A	B	A	B
Check	0	30 a	39a	46a	43a	62a	58a	32a	32a
2,4-D	16	29 a	26abc	41b	22b	51b	46b	31a	29b
Picloram (202)[a]	.5	30 a	28abc	37c	21b	53b	30c	31a	28b
Picloram (202)	1	37 a	17bcd	26d	13c	43c	14d	29b	21c
Picloram (22K)	2	36 a	24bc	28d	13c	43c	8e	22b	21c
Picloram (212)	2.5	35 a	18bcd	7e	6b	32d	5ef	19c	11d
Picloram (212)	5	30 a	13cd	8e	2e	13e	8e	10d	9d
Picloram (212)	10	27 a	8d	1f	0e	6f	0f	10d	3e

Values within columns followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

[a]For formulation see page 32.

oz/A decreased considerably by harvest time (Table 2) relative to the number of Canada thistle shoots per square yard counted in June (Table 1). Canada thistle receiving these treatments were spindly, shorter than the wheat, and appeared to produce less flower heads.

The Canada thistle density in 1969 relative to 1967 increased from 30 to 62 plants per square yard on the check plot, and from 29 to 51, 30 to 53, and 37 to 43 plants per square yard, respectively on plots treated with 2,4-D, and .5 and 1 oz/A of picloram (A) (Table 1). Hodgson (3) noted a similar temporary increase in the Canada thistle stand with applications of nitrogen fertilizer. The increase in Canada thistle density in this study may also be partly due to the application of fertilizer.

In 1970 the Canada thistle density decreased considerably on all plots except those with a low thistle density, namely, the 5 and 10 oz/A picloram (A) treatments and all picloram (B) treatments (Table 1). On the check plots the number of Canada thistle plants decreased from 62 to 32 plants per square yard. This reduction in density may be due in part to the reduction in fertilizer available. Gupta[3] observed a similar reduction from a cover of more than 90% Canada thistle in 1967 to about 40% in 1968 without the use of herbicides.

Canada thistle control with picloram at 10 oz/A or two applications of 5 oz/A a year apart was still very good three years after application, both received a rating of 9 (Table 2). Two applications of 2.5 oz/A maintained satisfactory control after three years, a rating of 7. The remaining thistles were weak and more easily controlled with cultivation.

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[3]Gupta, R. K. 1968. Chemical control of Cirsium arvense (L.) Scop. and Sonchus arvensis L. in relation to ecology of saline lake-shore vegetation. Masters Thesis Department of Plant Science, University of Alberta.

Table 2. Canada thistle control and crop damage for four years with eight treatments applied in 1967 (A) and in 1967 and 1968 (B).

Treatment[a]	Rate (oz/A)	1967	1968		1969		1970	
		A	A	B	A	B	A	B
		Canada thistle control[b]						
2,4-D	16	6	1	3	1	1	1	1
Picloram 202	.5	5	1	4	1	1	1	1
Picloram 202	1	6	2	6	1	2	1	1
Picloram 22K	2	5	4	8	3	5	1	2
Picloram 212	2.5	6	5	9	5	7	3	5
Picloram 212	5	8	7	9	7	9	6	7
Picloram 212	10	9	9	9	9	9	7	8
		Crop damage[b]						
2,4-D	16	1	1	1	1	1	1	1
Picloram 202	.5	1	1	2	1	1	1	1
Picloram 202	1	2	1	4	1	1	1	1
Picloram 22K	2	2	2	4	1	1	1	1
Picloram 212	2.5	3	2	5	1	1	1	1
Picloram 212	5	4	4	7	3	4	1	1
Picloram 212	10	6	5	8	4	5	1	2

[a]For formulation see page 32.

[b](1 no effect, 9 complete kill).

It would appear from a comparison of the number of Canada thistle shoots per square yard for treatment (A) and (B) in 1968, 1969, and 1970 (Table 1), that control with two applications of picloram at 2.5 oz/A was not significantly different from one application at 5 oz/A ($P < .05$).

A smooth-leaf form of Canada thistle appeared to be more tolerant to picloram than was the spiny form. The foliage of the smooth-leaf form was rapidly killed but it showed a more vigorous recovery, which is in agreement with observations made by Friesen (2).

Crop injury under the drought conditions of 1967 was relatively light (Table 2). This is in agreement with the work of Keys (6) who found that under drought conditions crop deformities were minimized. Wheat yields (Table 3) for all treatments in 1967 were greater, though not significantly greater, than the yield of the check plots.

In 1968 with the movement of the picloram into the root zone, crop injury on plots receiving a second application (B) increased relative to 1967 injury (Table 2). Picloram at 2.5 oz/A applied in two successive years showed as much injury in 1968 as the residue from 10 oz/A applied in 1967, a rating of 5. In 1968 wheat yields (Table 3) on all plots treated in 1967 with picloram at 1 to 10 oz/A were significantly better than on the check and 2,4-D plots. Yield on plots receiving 2.5 oz/A of picloram both years was significantly greater than on the check plots but significantly less than on the 2,4-D plots.

In 1969 only 5 and 10 oz/A of picloram showed any crop injury (Table 2). Wheat yield (Table 3) was greatest on the 2.5 oz/A (A) treatment, and the repeat application, (B) treatment, was equal to the check. However, the wheat yields for the repeat application of 5 and 10 oz/A were reduced significantly from the check. In 1970 wheat yield for both the single (A) and the double (B) 5 and 10 oz/A picloram applications was significantly

Table 3. Wheat yield (bu/A) for four years with eight treatments applied in 1967 (A) and in 1967 and 1968 (B).

Treatment[a]	Rate (oz/A)	Yield, bushels per acre						
		1967	1968		1969		1970	
		A	A	B	A	B	A	B
Check	0	9.5a	9.7c	9.4c	33.5ab	33.2c	12.6de	13.2c
2,4-D	16	15.9a	10.8c	19.0a	29.3c	25.5d	12.2e	12.4d
Picloram 202	.5	14.6a	10.5c	19.5a	34.2ab	36.9b	12.3e	12.5d
Picloram 202	1	12.3a	13.6b	19.1a	34.2ab	27.5d	13.7c	12.8cd
Picloram 22K	2	12.9a	18.1a	13.9b	32.8ab	42.0a	13.0d	12.8cd
Picloram 212	2.5	14.6a	13.6b	14.6b	35.0a	33.0c	13.6c	13.3c
Picloram 212	5	12.5a	17.9a	5.8d	32.3b	27.0d	14.4b	14.1b
Picloram 212	10	12.4a	13.6b	1.5e	33.5ab	22.0e	15.2a	14.6a

Values within columns followed by the same letters are not significantly different at the 5% level according to Duncan's Multiple Range Test.

[a]For formulations see page 32.

better than all the other treatments.

Comparing the repeat application of picloram (B) at 2.5 oz/A with one application at 5 oz/A (A) yields were not significantly different ($P < .05$) for 1968, 1969, and 1970. However, crop injury (Table 2) was considerably less at 2.5 oz/A than 5 oz/A.

Crop injury was greater at a low fertility level (Table 4). The 8 oz/A picloram treatment at a low fertility level caused more crop injury to wheat the second year after application, with a rating of 6, than did a similar 8 oz/A treatment in the year of application at a high fertility level, with a rating of 5. Although the data are not presented, yield at the high fertility level was not significantly affected by any of the treatments one year after application.

Barley also showed increased tolerance to picloram at a high fertility level. At a low fertility level barley showed crop injury in the year of application from picloram at 4, 6, and 8 oz/A, and at 6 and 8 oz/A one year later. At the high fertility level there was no barley injury one year after application of the herbicide.

Oats showed considerable tolerance to picloram. The only visible injury was in the year of application at low fertility, the 8 oz/A treatment caused a 2 day delay in maturity.

Picloram reduced the length of the peduncle of wheat plants to such an extent that many of the spikes failed to emerge above the flag leaf sheath. Similar effects have been noted by Nalewaja (7). Picloram also caused onion leafing or inrolling of the flag leaf and flag leaf sheath causing many of theemerging spikes to be twisted and bent but the arrangement of the spikelets was not altered.

Wheat harvested from picloram treated plots showed no detrimental effects on the milling and baking quality. On picloram treated plots

Table 4. Crop damage with five rates of picloram and two rates of fertilizer.

Crop	Year	16 lb. N and 16 lb. P_2O_5 Picloram[a] (oz/A)					60 lb. N and 16 lb. P_2O_5 Picloram[a] (oz/A)				
		1	2	4	6	8	1	2	4	6	8
Wheat	1	3	5	6	7	8	1	1	2	4	5
	2	1	1	4	5	6	1	1	3	4	5
	3	1	1	1	2	3	-	-	-	-	-
Barley	1	1	1	2	5	7	1	1	1	2	3
	2	1	1	1	2	2	1	1	1	1	1
Oats	1	1	1	1	1	2	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1	1

[a] Applied in year one.

[b] (1 no effect, 9 complete kill).

the percent protein in wheat increased each year (Table 5). The percent protein from wheat grown on check plots varied from 12.8 percent in 1967 to 17.2 percent in 1969. The 100 kernel weight on picloram treated plots decreased in 1967 but increased in 1968 and 1969. Nalewaja (7) has suggested that an increase in protein may possibly result from a reduced proportion of endosperm in the smaller kernels. Nalewaja (7) reports Lucken, working with fertility restoration in wheat, observed that kernels were larger and higher in protein from plants with partial sterility, and therefore suggests that picloram by causing some sterility results in the remaining kernels being larger and higher in percent protein.

Each year the percent germination was determined on two hundred kernels harvested from the treated plants. Germination was not affected by any of the treatments.

Considering the movement and persistence of picloram (5), Canada thistle control (Table 1 and 2), and the effects on cereal crops (Table 3, 4, and 5), it appears that satisfactory Canada thistle control in cereals can be obtained with picloram. In wheat, the most sensitive of the three cereals tested, two applications of picloram formulation 212 at 2.5 oz/A, high fertility, and a competitive crop provided satisfactory control of Canada thistle with limited crop injury.

Table 5. Percent protein[a] and 100 kernel weight of wheat for four years eight treatments applied in 1967 (A) and in 1967 and 1968 (B).

Treatment[b]	Rate (oz/A)	1967	1968		1969		1970	
		A	A	B	A	B	A	B
		Percent protein						
Check	0	12.8c	14.7d	14.6g	17.2bc	17.1c	12.3c	12.4d
2,4-D	16	13.3b	14.5d	15.8c	17.0c	17.1c	11.8c	12.1de
Picloram 303	.5	13.3b	14.2e	15.5f	17.4b	17.3bc	11.9c	12.1de
Picloram 202	1	13.5b	14.0e	16.1d	17.4b	17.5b	11.9c	12.5cd
Picloram 22K	2	13.2b	15.5c	17.3c	17.2bc	17.4b	12.3c	13.0c
Picloram 212	2.5	13.3b	15.6c	17.9b	17.3b	17.5b	13.2b	11.9c
Picloram 212	5	14.5a	16.2b	20.9a	17.4b	18.6a	13.4a	13.6b
Picloram 212	10	14.6a	18.0a	20.5a	18.0a	18.7a	13.7a	14.6a
		Hundred kernel weight (g)						
Check	0	3.2abce	2.5c	2.5c	2.5e	2.5c	3.8a	3.8a
2,4-D	16	3.4a	2.5c	2.5c	2.7cd	2.7b	3.7a	3.8a
Picloram 202	.5	3.3ab	2.5c	2.5c	2.6d	2.7b	3.8a	3.8a
Picloram 202	1	3.3a	2.5c	2.6b	2.8bc	2.7b	3.8a	3.8a
Picloram 22K	2	3.3abc	2.5c	2.6b	2.7c	2.7b	3.8a	3.8a
Picloram 212	2.5	3.2e	2.7a	2.6b	2.8bc	2.7b	3.7a	3.8a
Picloram 212	5	3.2bce	2.6b	2.6b	2.9ab	2.8ab	3.7a	3.7a
Picloram 212	10	3.1e	2.6b	2.7a	2.9a	2.8a	3.8a	3.7a

Values within columns followed by the same letters are not significantly different at the 5% level according to Duncan's Multiple Range Test.

[a]Zero percent moisture

[b]For formulation see page 32.

ACKNOWLEDGEMENTS

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SECTION 3

Environment and Herbicide Effects on Canada Thistle Ecotypes[1]

James H. Hunter[2] and Leon W. Smith[3]

Abstract. Root sections of seven Canada thistle (Cirsium arvense (L.) Scop.) ecotypes were grown under 8-, 12-, 14- and 16-hr photoperiods at 60 70 and 80F. Flowering occurred in all ecotypes under a 16-hr photoperiod. At the 14-hr photoperiod five ecotypes flowered, three were temperature dependent. Shoot and root development and plant height varied with ecotype. Both the root-to-shoot ratios and the number of shoot buds formed on the roots were inversely related to temperature and length of photoperiod. Herbicides tested for their effects on Canada thistle were 4-amino-3,5,6-trichloropicolinic acid (picloram), 3,6-dichloro-o-anisic acid (dicamba) and (2,4-dichlorophenoxy)acetic acid (2,4-D). Control of top growth increased with increasing temperature. Similarly, root control was maximum at 80F, at which temperature there were few fleshy roots. Picloram, unlike 2,4-D and dicamba, caused little leaf damage, but completely destroyed the root system.

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INTRODUCTION

Canada thistle (Cirsium arvense (L.) Scop.) can be found throughout the northern half of the United States and the southern part of most of the Canadian provinces (5). It is one of the most common weeds in Montana, Idaho, Oregon, and Washington, and causes heavier losses in crop yield than any other perennial weed (10). Calculated from a survey made by Alex (1), Manitoba, Saskatchewan, and Alberta have 22 million acres of cultivated land infested with Canada thistle. Friesen and Shebeski (7) reported 7.7 percent of the 142 Manitoba grain fields sampled contained 10 or more plant shoots per square yard.

Canada thistle is well adapted to a wide range of conditions, but grows best in deep, productive, well-aerated soils, and where temperatures are moderate and rainfall is 16 to 30 inches (2, 11).

Several Canada thistle varieties (5) and ecotypes (9) have been described. They show a differential response to several herbicides (3, 12, 16). Cords (4) suggested that temperature was a factor in the susceptibility of Canada thistle ecotypes to (2,4-dichlorophenoxy)acetic acid (2,4-D). Stomatal number and area, quantity of ether soluble leaf cuticle waxes, and relative leaf weight vary significantly among Canada thistle ecotypes, but there appears to be no particular relationship of these factors to the varied response of the plants to 2,4-D[4]. Light quality can change the susceptibility of some ecotypes to 2,4-D (6). Smith et al. (16) observed that metabolites of 3-amino-s-triazole (amitrole) appeared more rapidly in amitrole resistant ecotypes and that the presence of these metabolites could be influenced by light and temperature.

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[4]Hodgson, J. M. 1969. Varied response of Canada thistle and bindweed plants to herbicides. Paper presented at the Washington State Weed Control Association, Yakima, Washington, U. S. A.

Saidak[5] observed that epinasty, chlorosis, and necrosis developed more rapidly in the shoots of C. arvense var. mite than in C. arvense var. horridum plants treated with 4-(2,4-dichlorophenoxy)butyric acid (2,4-DB), 2,4-D, amitrole, 3,6-dichloro-o-anisic acid (dicamba) and 4-amino-3,5,6-trichloropicolinic acid (picloram). Var. horridum is more resistant to 2,4-DB and more susceptible to amitrole than var. mite. He suggested there may be a varietal difference in the growth rate, or distribution of the roots, or both.

In the study described here, the objectives were to assess the influence of temperature, photoperiod, and herbicides on the growth and chemical control of several Canada thistle ecotypes.

MATERIALS AND METHODS

Root sections of Canada thistle varieties and ecotypes were obtained as follows: Cirsium arvense var. mite and var. horridum, Dr. W. Saidak, C. D. A. Research Station, Harrow, Ontario; YM, G1 and FI ecotypes, Dr. D. Bayer, University of California (originally from the collection of Dr. J. Hodgson, U. S. D. A., Boseman, Montana); Fergus, collected near Fergus, Ontario by L. W. Smith, University of Guelph (August, 1967); Stratford, collected near Stratford, Ontario by P. D. Jordon, University of Guelph (July, 1968). Voucher specimens of these ecotypes and varieties have been placed in the University of Guelph herbarium and living material is being maintained in the weed garden.

The plants were maintained in growth rooms under a 16-hr photoperiod of 2,000 ft-c of artificial light, a day-night temperature of 77 and 70F respectively, and a relative humidity of approximately 70 per cent.

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[5]Saidak, W. J. 1966. Differential reaction of Canada thistle varieties to certain herbicides. Res. Rep. Natl. Weed Com. (East. Sec.) p. 212.

Young shoots of the seven ecotypes, the regrowth from detopped rootstalks, with attached roots of equal length, were selected for uniformity and planted in six-inch plastic pots. After one week in the original growth room, the plants were transferred to growth cabinets under several different temperatures (60, 70, 80F) and photoperiods (8-, 12-, 14-, 16-hr). As only three growth cabinets were available, the plants were grown at the three different temperatures and one photoperiod at a time. Treatments were replicated twice.

Observations were made periodically on plant height and time to flowering. After 12 weeks growth for the 8-hr photoperiod and 8 weeks growth for the 12-, 14-, and 16-hr photoperiods, at which time the plants appeared to be physiologically of equal age, the fresh and dry weights of foliage and roots were recorded and the number of new shoot buds formed on the rootstalks was counted.

The influence of the three different temperatures (60, 70, 80F) on the effects of three herbicides on five of the ecotypes was also studied. Plants were established as previously described and grown in growth cabinets at three temperatures (60, 70, 80F) under a 16-hr photoperiod. After 5 weeks the plants were sprayed with 2,4-D and dicamba at 16 oz/A and picloram at 2 and 4 oz/A. Treatments were replicated twice.

Observations were made periodically of the top growth control. Dry weight of roots was recorded 6 weeks after treatment.

RESULTS AND DISCUSSION

Although variation occurred in the growth of individual Canada thistle varieties and ecotypes several points were of interest. At the 8- and 12-hr photoperiods, none of the ecotypes flowered, while at the 16-hr photoperiod they all flowered irrespective of temperature (Fig. 1). At the 14-hr photoperiod, five of the seven ecotypes flowered, three of which were

Figure 1. Influence of the length of the photoperiod (12-hr bottom and 16-hr top) on the growth of Canada thistle var. mite at 60F (left) and 70F (right).

temperature dependent. G1 and var. mite flowered at all temperatures. FI and var. horridum only at 70 and 80F and Stratford only at 80F. YM and Fergus did not flower under a 14-hr photoperiod. Also, the time to flowering varied among ecotypes. G1 and var. mite flowered first, usually within 40-60 days while var. horridum took the longest to flower, approximately 60-80 days.

The root and shoot growth of the ecotypes was also quite variable under the different temperature and photoperiod regimes (Table 1). The root-to-shoot ratio was inversely related to temperature and length of photoperiod. The average root-to-shoot ratios for the 8- and 16-hr photoperiods at 60, 70 and 80F were 3.4, 3.2, .6 and 1.7, .7, .5 respectively. As the photoperiod increased from 8 to 16-hr at 70F the average root-to-shoot ratio decreased from 3.2 to .7. At low temperatures and short photoperiods root growth was predominant over shoot growth. However, when the temperature was increased to 80F there was a change in emphasis from root growth to shoot growth. At 8- and 12-hr photoperiods all plants remained in the rosette stage, while at the 16-hr photoperiod the plants tended to bolt and rapidly form flower heads. From visual observations at the 16-hr photoperiod, growth of shoots was best at 70F, it was slightly reduced at 60F and was greatly reduced at 80F. Plants at 80F flowered sooner than plants at 60 and 70F, but the plants were taller and more robust at the lower temperatures.

The order of the ecotypes by height was not constant for the three temperatures, but the Fergus ecotype was always the shortest plant at flowering.

The number of shoot buds formed on the roots, like the amount of root growth, was greatest at 60 and 70F temperatures and at the 8- and 12-hr photoperiodic regimes (Table 2). As the temperature was increased

Table 1. Influence of temperature on root and shoot growth and root-to-shoot ratio of Canada thistle ecotypes at 8, 12, 14, 16 hour photoperiods.

Ecotypes	Dry weight (g) of roots and shoots								
	60F			70F			80F		
	Root	Shoot	Root/Shoot	Root	Shoot	Root/Shoot	Root	Shoot	Root/Shoot
				8 hour photoperiod					
Fergus	10.6	3.6	2.9	9.4	3.5	2.7	7.0	11.9	0.6
Stratford	14.8	3.3	4.5	15.9	4.3	3.7	5.5	15.6	0.4
Mite	8.7	2.4	3.6	9.0	3.6	2.5	6.6	8.2	0.8
Horridum	13.4	4.3	3.1	7.4	3.0	2.5	6.2	9.3	0.7
YM	27.3	9.4	2.9	22.7	6.7	3.4	5.3	15.0	0.4
G1	14.6	2.8	5.2	18.9	3.0	6.3	9.8	12.2	0.8
FI	11.3	6.6	1.7	13.0	8.0	1.6	3.8	12.2	0.3
Average			3.4			3.2			0.6
				12 hour photoperiod					
Fergus	4.9	1.6	3.1	6.3	2.3	2.7	2.4	2.9	0.8
Stratford	9.2	1.6	5.8	12.2	2.6	4.7	5.1	3.5	1.5
Mite	5.9	1.7	3.5	9.4	2.3	4.1	3.6	3.2	1.1
Horridum	7.5	1.4	5.4	7.2	1.7	4.2	2.7	3.3	0.8
YM	7.5	2.0	3.8	5.5	1.8	3.1	2.6	5.3	0.5
G1	8.8	1.6	5.5	6.0	1.5	4.0	2.8	2.5	1.1
FI	7.2	2.0	3.6	9.4	3.8	2.5	2.5	4.2	0.6
Average			4.4			3.6			0.9

Table 1 cont'd.....

Table 1 (cont'd)

Ecotypes	Dry weight (g) of roots and shoots								
	60F			70F			80F		
	Root	Shoot	Root/Shoot	Root	Shoot	Root/Shoot	Root	Shoot	Root/Shoot
				14 hour photoperiod					
Fergus	3.2	2.2	1.5	3.3	4.2	0.8	2.1	5.4	0.4
Stratford	4.1	2.4	1.8	6.6	4.1	1.7	2.4	7.2	0.3
Mite	4.0	2.9	1.5	5.2	4.3	1.2	1.4	5.3	0.3
Horridum	2.5	1.7	1.5	3.0	5.2	0.6	2.1	6.5	0.3
YM	7.0	3.5	2.0	5.4	6.1	0.9	1.7	7.1	0.2
G1	3.7	1.9	2.0	4.6	5.1	0.9	2.8	7.2	0.4
FI	2.1	1.5	1.6	4.0	7.0	0.6	1.2	5.9	0.2
Average			1.7			0.9			0.3
				16 hour photoperiod					
Fergus	4.1	3.7	1.1	1.2	4.1	0.3	1.3	4.0	0.3
Stratford	3.7	1.9	2.0	4.5	3.0	1.5	3.8	5.0	0.8
Mite	2.8	1.8	1.6	2.2	4.4	0.5	1.8	3.5	0.5
Horridum	4.7	1.7	2.8	2.7	2.6	1.0	1.6	4.0	0.4
YM	3.7	1.9	2.0	2.3	3.3	0.7	1.8	5.4	0.3
G1	3.7	2.3	1.6	2.3	3.0	0.8	2.3	4.5	0.5
FI	2.2	3.4	0.7	1.7	5.9	0.3	2.0	4.5	0.4
Average			1.7			0.7			0.5

Table 2. Number of shoot buds formed on rootstocks of Canada thistle ecotypes at three photoperiods and three temperatures.

Ecotypes	No. of shoots for 3 photoperiods and 3 temperatures (F)								
	8 hr			12 hr			16 hr		
	60	70	80	60	70	80	60	70	80
Fergus	7	6	6	10	3	1.5	4.5	2	0
Stratford	12	11	3	11	10	2.5	5	3.5	2
Mite	3	4	2	5	8	2.5	7	7.5	3
Horridum	13	6	4	14	7.5	1	9.5	2.5	3
YM	21	16	2	15	7.5	2	18	10.5	1
Gl	18	16	12	10	4.5	14	3	4	0
FI	13	14	6	8	8	2.5	2.5	3.5	0
Average	12.4	10.4	5.0	10.4	6.9	3.7	7.1	4.7	1.3

within each photoperiodic regime, there was a decrease in the number of shoot buds formed on the roots. The number of shoot buds for the 8-hr photoperiod at 60, 70 and 80F were 12.4, 10.4 and 5.0 respectively.

The herbicide treatments showed various effects on the plants. They all affected top growth considerably. Swelling,splitting and deterioration throughout the root system was observed in picloram treated plants. The root and flower buds deteriorated and turned black. Some swelling occurred in the roots of 2,4-D treated plants immediately below the junction of the stem and root, otherwise little damage was evident. Dicamba effects were similar to 2,4-D, but caused more tissue destruction.

The rate at which 2,4-D, dicamba, and picloram killed the foliage of all ecotypes was much faster at 80F than at 60 or 70F. There was also a tendency for a faster top kill at 70F than at 60F, but it was less well marked. Generally as the temperature increased the control of top growth increased.

At 80F the amount of control of root growth was maximum (Table 3). However, as shown in Fig. 2, at 80F the root is mainly fibrous, with little or no rootstock from which regrowth could be initiated. This probably accounts for the better control obtained at this temperature.

Control of var. horridum and YM with 2,4-D and var. horridum and G1 with dicamba was greater at 60 than 70F even though the root was primarily rhizomal in nature at 60F. The slower kill of top growth may have permitted translocation farther into the root system, increasing the extent of control. Control with 2,4-D was better at 70F for the ecotype G1 which is considered resistant to 2,4-D. It did not suffer the same degree of leaf burn as the other ecotypes. Even though 2,4-D and dicamba gave a rapid top kill on var. mite, they showed a greater control at 70 than at 60F. The root-to-shoot ratios were .50 and 1.56 respectively,

Table 3. Percent reduction[a] in dry weight of roots of Canada thistle ecotypes at three temperatures and four chemical treatments.

Treatment		Ecotype and temperature (F)															
Chemical	Rate (oz/A)	Horridum			Mite			Stratford			G1			YM			Ave-
		60	70	80	60	70	80	60	70	80	60	70	80	60	70	80	rage
2,4-D	16	61	38	88	12	44	87	3	58	46	18	39	59	67	44	86	50
Dicamba	16	58	46	52	18	51	92	36	81	67	68	26	84	68	56	77	59
Picloram	2	56	61	94	52	83	67	63	76	87	66	91	88	72	65	68	73
Picloram	4	60	82	92	42	89	87	68	86	83	73	92	100	56	75	55	76
Average		59	57	82	31	67	83	43	75	71	56	62	83	66	60	72	

L.S.D. 5%: temp. 2.76, ecotype 3.56, treatment 3.56, temp. x ecotype 8.71, temp. x treatment 8.71, treatment x ecotype 11.25, treatment x temp. x ecotype 27.56.

[a]Reduction as a percent of check plants.

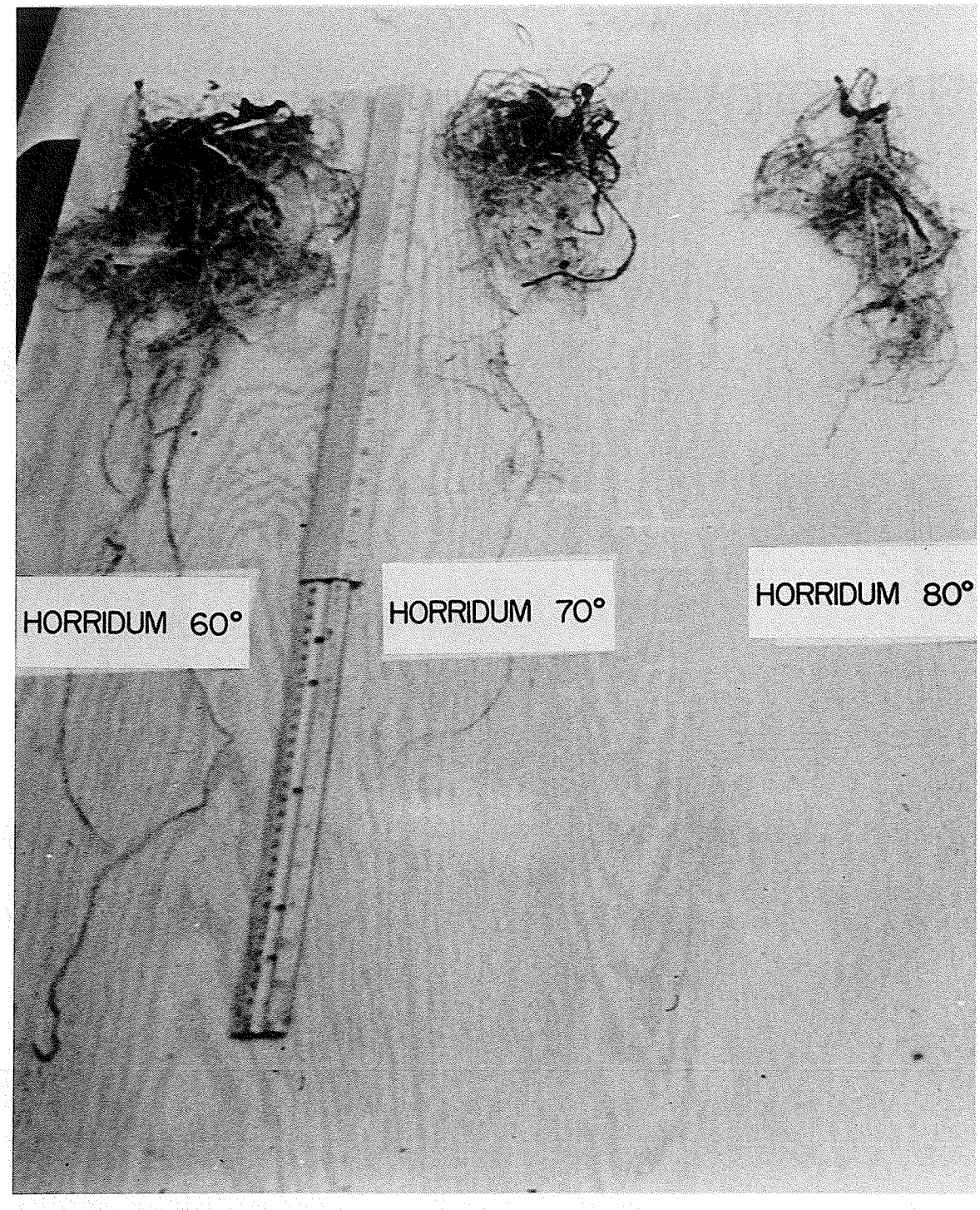

Figure 2. Influence of temperature (60, 70, 80F) on the root development of Canada thistle var. horridum grown at a 16-hr photoperiod.

and this was believed to account for these differences.

The results reported here and those reported elsewhere (8, 13, 14) indicate that 2,4-D and dicamba cause considerable disruption of Canada thistle leaf tissue, but cause little or no visible damage to root tissue. Picloram which causes little damage to leaf tissue except on var. mite, is rapidly translocated into the root and causes complete destruction of the root system, which confirms the findings of Lee, et al. (15).

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GENERAL DISCUSSION

The results in Section 1 and 2 clearly indicate that the movement and persistence of picloram were dependent on climate, rainfall and temperature, and therefore varied somewhat from year to year. Movement and persistence were greatest at the higher application rates and under higher rainfall. Dissipation was greatest in the upper soil profile, immediately following application, and at higher temperatures.

The persistence of picloram was greatly reduced by replacing a 5 oz/A application with two applications of 2.5 oz/A applied a year apart. This procedure capitalized on the rapid initial dissipation immediately following application, and reduced the quantity of picloram that moved out of the upper soil profile and into cooler depths.

The interactions of environment and ecotype indicate that Canada thistle has the genetic variability to adapt to a diverse environment with genetic change, which enables it to migrate into areas previously uninhabited by Canada thistle. At cool temperatures and short photoperiods the emphasis is on root growth rather than shoot growth and indicates the importance of controlling any regrowth in spring and fall to prevent an enlargement of the root system. The increase in the root-to-shoot ratio at low temperatures suggests that as Canada thistle migrates into the cooler northern regions destruction of the root system will become more difficult with herbicides that are not root absorbed.

The interactions of environment, herbicide and ecotype indicate that the effectiveness of each of the three herbicides compared, 2,4-D, dicamba, and picloram, was affected by the environment and the Canada thistle ecotype. The inherent differences in the physiological functions of ecotypes may necessitate the use of more than one herbicide in a rotation to

maintain satisfactory control of Canada thistle. The results indicate that picloram gave the most consistent results over all environments and ecotypes.

Picloram controlled not only the foliage but destroyed the root system of Canada thistle. In the field the Canada thistle plants that survived a treatment of picloram at 2.5 oz/A were severely weakened and more easily controlled by cultivation. Two applications of 2.5 oz/A of picloram applied for two successive years provided satisfactory Canada thistle control for three years, and was better than a single 5 oz/A application. More crop injury was noted the second year on plots following the second of two applications of picloram at 2.5 oz/A than on plots receiving a single 5 oz/A application but yield was not significantly reduced. However, the following year there was more injury from the single 5 oz/A application than from two applications of 2.5 oz/A.

Although the number of Canada thistle shoots increased with the application of fertilizer, control of Canada thistle appeared to be greater on plots with a high fertility level. Crop injury from picloram was greatly reduced at the higher fertility level. The increased competition from the fertilized crop was believed to have contributed considerably to increased control. This suggests that an increase in net returns can be obtained when fertilizer is used in combination with picloram. Hodgson (46) also noted a similar temporary increase in the Canada thistle stand with applications of nitrogen fertilizer, and showed that wheat yields and net returns increased when fertilizer was used in combination with 2,4-D. Comparison of the persistence of picloram in soil samples taken from the sunflower rows with those from the cereal crops, as well as a visual rating of persistence on plots at the high fertilizer level with plots at

the low fertilizer level, indicated that dissipation increased considerably in the presence of a competitive crop. The closely seeded cereal crops and especially those on high fertility plots, had a denser root system and were much more competitive crop than the sparsely seeded sunflowers in 24 inch rows. Meikle et al. (69) found that picloram decomposition was considerably greater in soil containing living plant roots than in soil alone.

Comparison of picloram alone and in combination with 2,4-D indicates that its effectiveness is increased considerably by the addition of 2,4-D (Section 2 Tables 1 and 2). Picloram at the rates applied to cereals does not control species of the Cruciferae family. Combination of picloram with the phenoxy herbicides controls a wider spectrum of weeds. Alley (6) found that half as much picloram was required for adequate Canada thistle control when this chemical was combined with 2,4-D. Krawiec and Morre (59) found that at least 25 percent of the picloram at a given treatment rate was replaceable by 2,4-D without a significant decline in overall herbicide effectiveness. Picloram increased the translocation of 2,4-D, but the reverse was not true (2).

The increased effectiveness of picloram and 2,4-D in combination permits the use of lower rates of picloram, thereby reducing the amount and persistence of residues in soil. However, it has been found (74) that a possible limitation to the combination is that the addition of 2,4-D to picloram increases wheat injury at the two to four leaf stage. Hodgson (46) found that wheat yields decreased as the time from Canada thistle emergence to treatment increased. He also reports that the susceptibility of Canada thistle to 2,4-D was greater in the early bud stage than in the bloom stage.

It will be necessary to make a compromise between the advantages of reducing the amount and persistence of residues in soil by decreasing the quantity of picloram and increasing the quantity of 2,4-D in combination, and the disadvantages of reducing wheat yield and Canada thistle control by increasing the time to application to avoid crop injury from the increased quantity of 2,4-D. A partial solution might be the removal of top growth by spring tillage to delay the early bud stage of Canada thistle relative to the cereal crop.

Comparison of the two picloram-2,4-D combinations, 202 and 212, indicates that in this study maximum Canada thistle control and crop yield with minimum crop injury were obtained where the combination of 2.5 oz/A of picloram with 5 oz/A of 2,4-D, formulation 212, was used.

This study indicates that picloram can be used in an effective Canada thistle program. The best results can be obtained where a combination of 2 to 3 oz of picloram with 4 to 6 oz of 2,4-D are applied for two successive years. Application should be made when the associated cereal is in the 3 to 4 leaf stage. Thistle control and crop yields are enhanced by high fertility and optimum growing conditions. The use of rotations commencing with the least sensitive cereal, oats $\angle$ barley $\angle$ wheat, and intensive cultivation are also recommended.

Control of regrowth in early fall with an application of 12-16 oz/A of a phenoxy herbicide will reduce the number of cultivations required. To reduce the initial cost of the herbicide and the possibility of lateral movement with run off water, it is recommended that spot treatment be used for scattered infestations.

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APPENDIX

APPENDIX A

Table 1. Recovery of Picloram from soil, at successive depths and sampling dates, applied at seven rates in 1967 (June 15).

Date samples	Depth (inches)	Recovery (ppb) of picloram applied (oz/A)						
		.38	.5	1	2	2.5	5	10
12/7/67	0-3	22	30	60	125	150	300	600
(.9)[a]	3-6	0	0	0	0	0	0	0
27/10/67	0-3	16	20	40	95	120	250	525
(4.4)	3-6	0	2	5	10	15	25	50
	6-12	0	0	0	0	0	2	4
30/5/68	0-6	6	8	15	35	50	105	225
(11.6)	6-12	0	0	2	8	5	10	22
	12-24	0	0	0	0	0	0	0
19/6/68	0-6	0	5	10	28	42	88	190
(12.3)	6-12	0	0	2	8	4	10	25
	12-24	-	-	0	0	0	0	0
28/8/68	0-6		0	0	4	12	28	70
(14.6)	6-12		0	0	6	2	8	30
	12-24		-	-	0	0	2	6
3/11/68	0-6				0	4	15	35
(16.8)	6-12				2	0	4	30
	12-24				0	0	0	8
23/5/69	0-6				2	5	15	40
(23.5)	6-12				2	0	4	25
	12-24				0	0	0	8
12/7/69	0-6				0	0	0	20
(25.2)	6-12				0	0	0	10
	12-24				-	-	0	5
1/9/69	0-6						0	0
(26.9)	6-12						0	0
	12-24						0	0
17/6/70	0-6						2	5
(36.5)	6-12						0	0
1/9/70	0-6						0	0
(39.1)	6-12						0	0

[a]Interval in months.

APPENDIX B

Table 2. Recovery of picloram from soil, at successive depths and sampling dates, applied at seven rates in both 1967 (June 15) and 1968 (June 19).

Date sampled	Depth (inches)	Recovery (ppb) of picloram applied (oz/A)						
		.38	.5	1	2	2.5	5	10
28/8/68	0-6	5	10	18	40	60	130	300
(14.6)[a]	6-12	0	0	5	15	8	20	35
(2.3)[a]	12-24	0	0	0	2	2	5	10
3/11/68	0-6	0	0	5	20	35	100	230
(16.8)	6-12	0	0	0	10	8	15	35
(4.5)	12-24	-	-	0	5	2	5	10
23/5/69	0-6			8	20	35	100	230
(23.5)	6-12			0	10	8	15	35
(11.2)	12-24			0	5	2	5	10
12/7/69	0-6			0	10	20	80	180
(25.2)	6-12			0	5	4	10	30
(12.9)	12-24			-	4	2	4	10
1/9/69	0-6				0	0	20	65
(26.9)	6-12				0	0	2	10
(14.6)	12-24				0	0	2	5
16/6/70	0-6					2	10	50
(36.5)	6-12					0	2	10
(24.2)	12-24					-	2	5
1/9/70	0-6					0	2	8
(39.1)	6-12					0	0	0
(26.8)	12.24					-	0	0

[a]Interval in months.

APPENDIX C

Table 3. Wheat yield for four years with eight treatments applied in 1967 (A) and in 1967 and 1968 (B).

Treatment		Rate (oz/A)	Yield (bushels per acre) 1967	1968	1969	1970
Check	A	0	9.5a	9.7bc	33.5abc	12.6b
	B			9.4bc	22.2abc	13.2ab
2,4-D	A	16	15.9a	10.8bc	29.3bcd	12.2b
	B			19.0a	25.5cd	12.4b
Picloram 202	A	.5	14.6a	10.5bc	34.2abc	12.3b
	B			19.5a	36.9ab	12.5b
Picloram 202	A	1	12.3a	13.6ab	34.2abc	13.7ab
	B			19.1a	27.5bcd	12.8b
Picloram 22K	A	2	12.9a	18.1a	32.8abcd	13.0ab
	B			13.9ab	42.0a	12.8b
Picloram 212	A	2.5	14.6a	13.6ab	35.0abc	13.6ab
	B			14.6ab	33.0abc	13.3ab
Picloram 212	A	5	12.5a	17.9a	32.3abcd	14.4ab
	B			5.8cd	27.0bcd	14.1ab
Picloram 212	A	10	12.4a	13.6ab	33.5abc	15.2a
	B			1.5d	22.0d	14.6ab

Values within columns followed by the same letters are not significantly different at the 5% level according to Duncan's Multiple Range Test.

APPENDIX D

Table 4. Wheat yield for two years with eight treatments applied in 1969.

Treatment	Rate (oz/A)	Yield (bushels per acre) 1969	1970
Check	0	15.3d	18.0a
Picloram[a]	1	32.7a	21.8a
Picloram	2	30.4ab	21.0a
Picloram	3	39.5ab	22.4a
Picloram	4	27.7ab	20.5a
Picloram	5	24.1bc	21.5a
Picloram	6	18.3cd	20.0a
Picloram	8	17.1d	20.1a

Values within columns followed by the same letters are not significantly different at the 5% level of significance according to Duncan's Multiple Range Test.

[a]Triisopropanolamine salt with 1 lb. of picloram and 2 lb. of 2,4-D per American gal.

APPENDIX E

Table 5. Dry weight (grams) of roots of Canada thistle ecotypes at three temperatures with various chemical treatments.

Treatment			Ecotype and temperature (F)													
Chemical		Rate (oz/A)	Horridum			Mite			Stratford			G1			YM		
			60	70	80	60	70	80	60	70	80	60	70	80	60	70	80
Check	1	0	4.0	2.7	2.9	4.1	3.9	1.9	7.6	8.6	2.1	6.4	4.0	2.6	6.8	4.2	1.1
	2		3.7	3.4	2.1	1.9	4.8	2.0	2.7	8.4	2.7	5.3	3.7	2.5	3.6	3.3	1.1
2,4-D	1	16	1.3	3.8	0.4	4.9	2.8	0.5	4.9	3.1	1.5	5.2	2.3	1.0	2.0	2.6	0.0
	2		1.7	1.5	0.2	2.3	2.1	0.0	5.1	4.1	1.1	4.4	2.4	1.1	1.4	1.6	0.3
Dicamba	1	16	1.1	1.7	1.0	2.5	2.3	0.3	3.2	1.7	1.0	1.1	2.7	0.5	1.7	1.9	0.2
	2		2.1	1.6	1.4	2.4	2.0	0.0	3.4	1.6	0.6	2.6	3.0	0.3	1.6	1.4	0.3
Picloram	1	2	2.4	1.5	0.2	1.7	0.5	0.4	1.8	2.1	0.4	2.7	0.2	0.7	1.7	1.5	0.4
	2		1.2	0.9	0.1	1.2	1.0	0.9	2.0	2.0	0.2	1.3	0.5	0.1	1.2	1.1	0.3
Picloram	1	4	1.7	0.3	0.2	2.0	0.6	0.2	1.8	1.6	0.2	1.9	0.4	0.0	2.1	1.1	0.6
	2		1.4	0.8	0.2	1.5	0.4	0.3	1.5	0.8	0.6	1.3	0.2	0.0	2.5	0.8	0.4

APPENDIX F

Morphological characteristics of Canada thistle varieties and ecotypes.

mite - leaves arachnoid - downy, lanceolate - oblanceolate; minutely spinose, flexible, of equal length; primary and branch leaves flat - subundulate, minutely dentate, entire to lobulate; stem - leaves undulate, lobulate; brachiate, heads clustered terminating upper branches, sweet scented lilac pink flowers.

horridum - leaves glabrous, lanceolate, symmetrical, sinuate, medium cleft; pinnately lobed, one of the points of each lobe is erect on the leaf blade; spines numerous, long, stiff, extending down the stem for some distance.

Fergus - leaves glabrous, narrow, linear, lancelolate, sinuate, medium cleft; lobes slender, spaced well apart; spines numerous, medium length, lobe-end spines are long; ramose, with pale pink flowers.

Stratford - leaves arachnoid - downy, lanceolate, flat - subundulate, semi - entire - lobulate; spines numerous, short - medium length, stiff.

YM - leaves glabrous, lanceolate, sinuate, deeply cleft; pinnately lobed, one of the points erect, lobes may be spaced well apart, spines numerous, long, stiff; ramose.

G1 - leaves lanceolate - oblanceolate, light green, flat - subundulate, shallow cleft; spines few, flexible; ramulose; flowers dark pink, bract spines have the purple color of the tip extending down the bract vein.

FI - leaves oblanceolate, sinuate - pinnately lobed, medium cleft; spines numerous, long, stiff; ramulose.

APPENDIX G

Bioassay Technique

Ten days after seeding, the eight plants per pot were thinned to five uniform plants. At 14, 41, and 28 days after seeding the plants within each pot were scored for uniformity. If more than one plant per pot varied the pot was removed from the experiment; when two or more pots per sampling date and soil depth were removed due to variability, the experiment was repeated.

The eight replicates of the unknowns were compared to the standards and if two or more of the replicates varied by more than one unit the experiment was repeated. The soybean standards increase by a unit of 2 ppb (0, 2, 4, 6, 8 --), the sunflower standards increased by a unit of 25 ppb.

Variability was due mainly to technical errors, not the sensitivity of the bioassay test. The sensitivity of the bioassay with soybeans was considered to be within 2 ppb and with sunflowers to be within 25 ppb.

It was assumed that the soil from an acre in area and 6 inches deep weighed 2 million lb. Therefore a 1 oz/A application was equivalent to 31.25 ppb.

$$\frac{1 \text{ oz.}}{\text{Acre}} \times \frac{1 \text{ lb.}}{16 \text{ oz.}} \times \frac{1 \text{ acre}}{2{,}000{,}000 \text{ lbs}} \times \frac{1000}{1000} = \frac{31.25}{\text{billion}}$$

The percent recovery was obtained by dividing the ppb detected by the bioassay plants by the ppb of picloram originally applied.

One application of 1 oz/acre.

$$\frac{\text{ppb detected}}{31.25 \text{ ppb}} \times 100 = \% \text{ recovery}$$

Two applications of 1 oz/acre

$$\frac{\text{ppb detected}}{62.5 \text{ ppb}} \times 100 = \% \text{ recovery}$$