# BIOACTIVITY AND PERSISTENCE OF FALL AND SPRING APPLICATIONS OF SOIL-APPLIED HERBICIDES

A Thesis

Submitted to the Faculty

of

Graduate Studies

The University of Manitoba

by

David Allan Pchajek

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

Department of Plant Science

March 1982

# BIOACTIVITY AND PERSISTENCE OF FALL AND SPRING APPLICATIONS OF SOIL-APPLIED HERBICIDES

BY

DAVID ALLAN PCHAJEK

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

## ACKNOWLEDGEMENTS

The author would like to express his sincere gratitude to Dr. I.N. Morrison for his guidance and counselling during preparation of this thesis and for financial assistance. Thanks are also extended to Dr. E.H. Stobbe, Dr. G.R.B. Webster, and Dr. M.K. Pritchard for their helpful assistance and review of this manuscript. Special appreciation is extended to the Pesticide Research Laboratory, Department of Soil Science for the use of their facilities for soil residue determinations.

I am also very grateful to Len Dushnicky for his technical assistance in preparation of the histological material, Denise Maurice for her assistance in the field experiments, and Len Sarna for his helpful suggestions and assistance with the residue studies.

Finally, I would like to thank my family, fellow students, and many friends for their constant support and encouragement during the course of my studies.

# TABLE OF CONTENTS


| | PAGE |
|---|---|
| LIST OF TABLES | v |
| LIST OF FIGURES | vii |
| LIST OF PLATES | viii |
| ABSTRACT | ix |
| INTRODUCTION | 1 |
| CHAPTER I - LITERATURE REVIEW | 3 |
| Bioactivity of Soil-Applied Herbicides | 4 |
| Site of Uptake | 4 |
| Morphological and Histological Responses | 7 |
| Factors Affecting Performance of Soil-Applied Herbicides | 10 |
| Soil Temperature | 10 |
| Soil Moisture | 13 |
| Soil Type and Organic Matter Content | 15 |
| Placement Into the Soil | 16 |
| Timing of Soil-Applied Herbicide Applications | 17 |
| Persistence of Soil-Applied Herbicides | 19 |
| Volatilization | 20 |
| Photodecomposition | 22 |
| Degradation | 22 |
| Persistence Under Prairie Conditions | 23 |
| CHAPTER II - FIELD STUDIES WITH FALL AND SPRING APPLICATIONS OF SOIL-APPLIED HERBICIDES | 26 |
| Introduction | 26 |
| Materials and Methods | 27 |
| Results | 33 |
| Flax Experiments | 33 |
| Rapeseed Experiments | 38 |

PAGE

Discussion .......... 43

Flax Experiments .......... 43
Rapeseed Experiments .......... 46

CHAPTER III - SOIL PERSISTENCE AND PHYTOTOXICITY .......... 50

Introduction .......... 50
Materials and Methods .......... 51

Sampling .......... 51
Determination of Soil Residues .......... 52
Phytotoxicity Studies .......... 54

Results .......... 55

Soil Persistence of Trifluralin, Dinitramine, and Triallate .......... 55
Phytotoxicity of Soil Residues .......... 65

Discussion .......... 85

CHAPTER IV - GERMINATION AND GROWTH OF RETRIEVED WEED SEEDS ... 93

Introduction .......... 93
Materials and Methods .......... 94

Seed Retrieval .......... 94
Germination and Seedling Growth .......... 95
Growth Room Studies .......... 96
Histological Studies with Yellow Foxtail .......... 97

Results .......... 98

Germination and Seedling Growth .......... 98
Growth Room Studies .......... 109
Histological Studies with Yellow Foxtail .......... 112

Discussion .......... 112

SUMMARY AND CONCLUSIONS .......... 122

Recommendations for Future Research .......... 124

LITERATURE CITED .......... 125

APPENDIX .......... 130

# LIST OF TABLES


| TABLE | | PAGE |
|---|---|---|
| 1 | Herbicide formulations, rates, and dates of fall and spring application in flax | 29 |
| 2 | Herbicide formulations, rates, and dates of fall and spring applications in rapeseed | 30 |
| 3 | The effect of fall and spring applications of several soil-applied herbicides on control of green foxtail and wild oats in flax, 1978 | 34 |
| 4 | The effect of fall and spring applications of several soil-applied herbicides on crop tolerance, crop density, and seed yield of flax, 1978 | 35 |
| 5 | Effects of fall and spring applications of several soil-applied herbicides on green foxtail and flax, 1979 | 36 |
| 6 | The effect of fall and spring applications of several soil-applied herbicides on control of green foxtail and wild oats in rapeseed, 1978 | 39 |
| 7 | The effect of fall and spring applications of several soil-applied herbicides on crop tolerance, crop density, and seed yield of rapeseed, 1978 | 40 |
| 8 | Effects of fall and spring applications of several soil-applied herbicides on green foxtail and rapeseed, 1979 | 41 |
| 9 | Shoot dry weight of wild oats grown in triallate-treated soil that was collected during the 1978 growing season | 81 |
| 10 | Shoot dry weight of wild oats grown in triallate-treated soil that was collected during the 1979 growing season | 82 |
| 11 | Percent germination of yellow foxtail seeds retrieved in the spring from plots treated in the previous fall with three dinitroaniline herbicides | 99 |

| TABLE | | PAGE |
|---|---|---|
| 12 | Percent germination of yellow foxtail seeds retrieved in the spring from plots treated in the previous fall with EPTC and emulsifiable (EC) and granular (G) formulations of triallate ................ | 100 |
| 13 | The effects of fall applications of EPTC and triallate on shoot and root lengths of yellow foxtail retrieved in the spring of 1978 and 1979 ........................ | 101 |
| 14 | The effects of fall applications of EPTC and triallate on percent germination and shoot and root lengths of wild oats retrieved in the spring of 1979 ............. | 110 |
| 15 | The effects of fall applications of dinitramine, pendimethalin, and trifluralin on percent germination and shoot and root lengths of wild oats retrieved in the spring of 1979 ................................ | 111 |
| 16 | Emergence and growth of yellow foxtail from seeds retrieved in the spring of 1979 following fall applications of dinitramine, pendimethalin, and trifluralin ........................................ | 112 |
| 17 | Emergence and growth of wild oats from seeds retrieved in the spring of 1979 following fall applications of dinitramine, pendimethalin, and trifluralin ........................................ | 113 |

# LIST OF FIGURES


| FIGURE | | PAGE |
|---|---|---|
| 1 | Persistence of fall and spring applications of trifluralin in 1978 and 1979 ........................ | 57 |
| 2 | Persistence of fall and spring applications of dinitramine in 1978 and 1979 ........................ | 59 |
| 3 | Persistence of fall and spring applications of EC and G formulations of triallate in 1978 ........... | 62 |
| 4 | Persistence of fall and spring applications of EC and G formulations of triallate in 1979 ........... | 64 |
| 5 | Phytotoxicity of soil residues of trifluralin, dinitramine, and pendimethalin to yellow foxtail ...... | 67 |
| 6 | Phytotoxicity of soil residues of EC and G formulations of triallate to wild oats ................ | 78 |
| 7 | Phytotoxicity of soil residues of EPTC to yellow foxtail ........................................ | 84 |
| 8 | The effects of fall applications of dinitramine, trifluralin, and pendimethalin on shoot and root lengths of yellow foxtail retrieved in the spring of 1978 ........................................ | 103 |
| 9 | The effects of fall applications of dinitramine, trifluralin, and pendimethalin on shoot and root lenghts of yellow foxtail retrieved in the spring of 1979 ........................................ | 105 |

# LIST OF PLATES


| PLATE | | PAGE |
|---|---|---|
| 1 | Growth of yellow foxtail in dinitramine-treated soil at different soil sampling dates | 70 |
| 2 | Growth of yellow foxtail in trifluralin-treated soil at different soil sampling dates | 72 |
| 3 | Growth of yellow foxtail in pendimethalin-treated soil at different soil sampling dates | 74 |
| 4 | Growth of wild oats in post-harvest soil samples taken from plots treated with granular (G) and emulsifiable concentrate (EC) formulations of triallate | 80 |
| 5 | Morphological injury symptoms on developing yellow foxtail seedlings grown from seed retrieved from fall-treated field plots | 108 |
| 6 | Longitudinal and transverse sections taken through the coleoptile node region of 10-day-old yellow foxtail seedlings | 116 |

# ABSTRACT

Pchajek, David Allan. M.Sc., The University of Manitoba, March, 1982. Bioactivity and Persistence of Fall and Spring Applications of Soil-Applied Herbicides. Major Professor; I.N. Morrison.

Field and laboratory experiments were conducted to investigate the efficacy and persistence of fall and spring applications of trifluralin, dinitramine, pendimethalin, EPTC, and triallate applied as preplant soil-incorporated herbicides in flax and rapeseed.

The herbicides used in the field experiments were applied in the fall and the spring at recommended application rates; as well an application at twice the recommended rate was applied in the fall. Field performance of the herbicides was assessed by comparing crop tolerance, weed control, and crop yields. With all herbicides tested, fall applications resulted in better crop tolerance and, with the exception of EPTC, comparable levels of weed control to the spring treatment. Triallate provided the least satisfactory weed control, primarily due to the abundance of resistant weed species.

The laboratory experiments included soil residue studies on trifluralin, dinitramine, and triallate as determined by glc analysis, bioactivity studies where phytotoxicity of soil-applied herbicides to susceptible weed species was determined in samples taken from the field plots at selected dates, and a study on uptake of herbicides by weed seeds in the soil.

The soil residue study indicated that considerable herbicide loss

occurred very shortly after application. On a sandy loam soil, there appeared to be no need for increasing the application rate of trifluralin when it was applied in the fall as residue levels were consistently higher than with a spring treatment. With a spring application of trifluralin at 0.84 kg/ha, 13 to 29% of the chemical present at time of seeding remained at the end of the growing season, while with a fall treatment at 1.12 kg/ha, 34 to 39% of the initial concentration remained at the end of the growing season. The granular formulation of triallate persisted at higher soil concentrations than the emulsifiable concentrate formulation, although initial levels were higher with the granules than with the emulsifiable concentrate formulation. Very little dinitramine remained in the soil at the end of the growing season.

The bioactivity studies parallelled the results of the persistence experiments. The results suggest that carryover of triallate, trifluralin, and pendimethalin may be sufficient to injure susceptible crops. No carryover problems should exist with EPTC and dinitramine.

The studies on uptake of herbicides by weed seeds in the soil showed that while germination of the seed was unaffected, seedling shoot development was markedly affected by trifluralin, dinitramine, and pendimethalin. Triallate and EPTC had no effect on germination or early seedling growth indicating that they were not adsorbed in sufficient quantities to induce injury.

Field performance of fall and spring applications of soil-applied herbicides is related to persistence, toxicity to susceptible weeds, and possibly, uptake of the herbicide by weed seeds in the soil.

# INTRODUCTION

In Western Canada, the use of soil-applied herbicides is a widespread practice among many farmers. These herbicides have been used as both fall and spring applications depending upon the cropping situation for which they are intended. Some of the herbicides that have been used as soil treatments include trifluralin, triallate, EPTC, and dinitramine. While considerable research has been done on field practices associated with the use of soil-applied herbicides, little information is available on comparable efficacy of fall and spring applications.

Current recommendations suggest the use of higher application rates when the soil-applied herbicide is used as a fall treatment. An exception to this rule is triallate which has a similar application rate for both fall and spring treatments. Numerous studies have indicated that considerable losses of herbicide may occur from time of fall application to after spring thaw, while at the same time providing adequate levels of weed control.

Considering that little information was available on comparable performance of fall and spring applications of soil-applied herbicides, this study was undertaken to determine the bioactivity of fall and spring applications of different soil-applied herbicides as related to timing of application, persistence, and influence on weed seeds. Field studies were conducted to evaluate the efficacy of fall and spring applications of trifluralin, dinitramine, pendimethalin, and triallate in rapeseed and triallate, EPTC, and trifluralin in flax. Further studies under laboratory conditions were conducted to assess persistence and bioactivity of soil-applied herbicides as well as to investigate uptake of herbicides by weed seeds in the soil.

# CHAPTER I

## LITERATURE REVIEW

Soil-applied herbicides are applied either as pre-plant incorporated or pre-emergent treatments, and generally control emerging weed seedlings in the soil, thereby preventing weed competition during the early stages of crop development. These chemicals belong to a number of herbicide families. In the dinitroaniline family, trifluralin (α,α,α-trifluro-2,6-dinitro-N,N-dipropyl-p-toluidine), dinitramine ($N^4$,$N^4$-diethyl-α,α,α-trifluro-3,5-dinitrotoluene-2,4-diamine), and pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] are used exclusively as soil-applied treatments. In the thiocarbamate family of herbicides, triallate [S-(2,3,3-trichloroallyl) diisopropylthiocarbamate] and EPTC (S-ethyl dipropylthiocarbamate) are also used solely as soil-applied herbicides. Of the above mentioned herbicides, only dinitramine and pendimethalin are not currently recommended for use in Manitoba.[1] Dinitramine was recommended but recently was withdrawn from the market.

This literature review will attempt to cover the bioactivity of selected soil-applied herbicides including reference to the sites of uptake and mechanism of action, factors influencing their field performance, and their persistence in the soil under various conditions.

---

[1] 1982 Guide to Chemical Weed Control, Agdex 641, Manitoba Agriculture.

## Bioactivity of Soil-Applied Herbicides

### Site of Uptake

Most of the soil-applied herbicides in use in Western Canada exert their activity on germinating weed seedlings early in their development. This results in failure of the developing shoot to emerge from the soil. For this to occur, the herbicide must exert its phytotoxic action on germination processes or on early root and shoot development.

Uptake of soil-applied herbicides by seeds in the soil prior to initiation of germination may enhance the activity of the chemical on germination and early seedling development. Research with soybean seed [*Glycine max* (L.) Merr.] has shown that uptake occurred at varying rates depending upon the herbicide and was influenced by temperature and concentration (Reider *et al*., 1970). Furthermore, absorption was not directly related to water uptake by the seed and could continue after seeds were fully imbibed. Scott and Phillips (1973) also reported variations in the amount and rate of absorption of several different herbicides by soybean seed from an aqueous solution. In soil, they found that the amount of atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine] and chlorpropham (isopropyl *m*-chlorocarbanilate) absorbed by soybean seed was greater than the amount transported to the seed as a result of imbibition of water and attributed the difference in uptake to diffusion of the herbicide to the seed in the soil.

Several researchers have found that herbicides can affect germination of seeds. Exposure to EPTC and butylate (*S*-ethyl diisobutylthiocarbamate) vapours significantly increased the germination of common lambsquarters (*Chenopodium album* L.) and velvetleaf (*Abutilon* theophrasti Medic.) seeds, whereas diallate [S-(2,3-dichloroallyl) diisopropyl-thiocarbamate] had no effect on germination of the weed seeds (Fawcett and Slife, 1975). In studies by Appleby and Brenchley (1968), germination of bluegrass (Poa pratensis L., var. Newport) and perennial ryegrass (Lolium perenne L., var. Linn) was severely inhibited when the seeds were sprayed with paraquat (1,1'-dimethyl-4,4'-bipyridinium salt).

In other work, glyphosate [N-(phosphonomethyl) glycine] stimulated germination of redroot pigweed (Amaranthus retroflexus L.) seeds but had no effect on four other weed species (Egley and Williams, 1978). In the same study, paraquat inhibited germination of johnsongrass [Sorghum halespense (L.) Pers.] and barnyardgrass [Echinocloa crusgalli (L.) Beauv.] , but had no effect on the broadleaf weed species. Schultz et al. (1968) reported that trifluralin had no effect on germination of corn (Zea mays L.) seed although subsequent root and shoot growth were affected. Thus, the activity of a herbicide has been shown to vary with the chemical and with the test species.

While uptake of herbicides by seeds and effects on seed germination have been reported, most reports in the literature attribute the activity of soil-applied herbicides to root and/or shoot uptake during early seedling development. Many investigators agree that for the dinitroaniline herbicides such as trifluralin and dinitramine, the shoot of monocots and the hypocotyl of dicots are the major sites of uptake (Prendeville et al., 1967; Rahman and Ashford, 1970; Barrentine and Warren, 1971a,b; Swann and Behrens, 1972). However, Parker (1965) reported that trifluralin appears to be more toxic to sorghum (Sorghum vulgare X sudanese, var. Sudax) following root uptake than shoot uptake.

Studies with EPTC have indicated that both root and shoot exposure can cause injury to a number of plant species. Dawson (1963) reported that exposure of barnyardgrass coleoptiles to EPTC-treated soil injured developing foliar leaves within the coleoptile, while root exposure did not lead to injury. Tests with pea (*Pisum sativum* L.) and corn indicated that EPTC was more effective when applied to the shoot zone than the root zone (Prendeville *et al.*, 1967). Using a variety of test species, Gray and Weierich (1969) determined that eight species, including barnyardgrass, were more sensitive to root exposure than shoot exposure to EPTC, while in three species, including sorghum and pea, shoot exposure resulted in more injury than root exposure. It seems apparent that the activity of EPTC relies upon both root and/or shoot uptake, depending upon the plant species involved.

Triallate and diallate are two herbicides that have been used for wild oat (*Avena fatua* L.) control in Western Canada. Molberg *et al.* (1964) showed that effective wild oat control and good wheat (*Triticum aestivum* L.) tolerance could be achieved with diallate and triallate if the herbicides were shallowly incorporated and the wheat was seeded below the treated layer of soil. The difference in activity on the two species was attributed to the fact that the sensitive stem apex of wild oats is pushed into the treated zone by the mesocotyl during emergence; whereas with wheat the apex remains close to the seed until much later in the course of plant development (Friesen *et al.*,1962; Banting, 1967).

Most of the research conducted with dinitroaniline and thiocarbamate herbicides has indicated that herbicide vapours play a major role in the activity of the chemicals in the soil. Swann and Behrens (1972) found that trifluralin vapours arising from the soil were effective in inhibiting root and shoot growth of foxtail millet [Setaria italica (L.) Beauv.] and proso millet (Panicum milaceum L.). Jacques and Harvey (1979) reported vapour absorption of several dinitroanilines including trifluralin and dinitramine by roots and shoots of oats (Avena sativa L.) and peas. Dawson (1963) showed EPTC vapours influenced the growth of barnyardgrass, while Miller and Nalewaja (1975, 1976) have demonstrated the phytotoxicity of triallate vapours to wild oat seedlings.

## Morphological and Histological Responses

As discussed in a review paper by Parka and Soper (1977) on the physiology and mode of action of dinitroaniline herbicides, these chemicals typically have been shown to inhibit lateral or secondary root development in many plant species. Many researchers have reported swelling of the root tips associated with lateral root inhibition as the most common morphological effect caused by dinitroaniline herbicides. For example, Bayer et al. (1967) reported that the most obvious effect of trifluralin on primary roots of cotton (Gossypium hirsutum L.) and safflower (Carthamus tinctorius L.) was increased radial expansion near the root tip along with lateral root inhibition in the treated soil region. Root aberrations on sugar beets (Beta vulgarus L.) were reported to occur following an application of dinitramine, but the exact type of aberration was not disclosed (Schweizer, 1979).

Besides having activity on roots, the dinitroaniline herbicides have been shown to affect shoot development. Schultz et al. (1967) reported that trifluralin at concentrations of 0.1 $\mu$M to 10 $\mu$M inhibited elongation of corn seedling coleoptiles. Trifluralin phytotoxicity to wild oats was much greater following shoot contact than root contact, with the former resulting in greater reductions in shoot length and dry weight than the latter (Friesen and Bowren, 1972). Rahman and Ashford (1970) found that trifluralin at 1.12 ppmw severely inhibited elongation of the mesocotyl and coleoptile of green foxtail [Setaria viridis L. (Beauv.)] and caused a marked swelling of these tissues near the coleoptile node. In studies with wild oats, Billet and Ashford (1978) demonstrated that trifluralin at 1.12 kg/ha induced extensive swelling of the mesocotyl, coleoptile, and coleoptile node and reduced extension of both the mesocotyl and coleoptile.

Research with other soil-applied herbicides has shown that EPTC affects shoot development of barnyardgrass seedlings (Dawson, 1963). Typically, injury appeared on the foliar leaves and was characterized by limited elongation of the leaves. As rates of EPTC increased, the severity of injury increased such that at the highest rates (4 ppmw to 6 ppmw) no leaf development occurred beyond the coleoptile. In Dawson's study, EPTC had little or no effect on the length of the coleoptiles.

Studies with wild oats have shown that triallate at 1.12 kg/ha does not significantly reduce coleoptile extension, although mesocotyl length may be reduced (Billet and Ashford, 1978). Often if the first leaf failed to emerge through the coleoptile tip, then it emerged through the side of the coleoptile. By exposing wild oat seedlings to triallate vapours, Miller and Nalewaja (1976) observed cessation of leaf elongation, leaf distortion, and darkening. As exposure time increased, the degree of growth inhibition increased.

Besides the studies on the gross morphological injury associated with some of the soil-applied herbicides, considerable research has been done at the histological level, especially with trifluralin.

Bayer et al. (1967) reported that trifluralin induced radial expansion near the root tip with the initial expansion occurring in the region of maximum elongation. These researchers also found evidence of disruption of mitosis, although mitotic activity was not affected in all cells. With corn, radial enlargement of the root tip and first internode following trifluralin treatment was due to swollen cortical cells (Schultz et al., 1967). Multinucleate cells were present in both root tips and in the region of the first internode. Later work by Lignowski and Scott (1971) and Mallory and Bayer (1972) supported the concept that radial enlargement seen in trifluralin-treated root tips was due to abnormal expansion of cortical cells.

Mallory and Bayer (1972) also found evidence that lateral root initiation in cotton was arrested by trifluralin prior to completion of cell division of the pericycle. This was not evident in safflower, where normal lateral root primordia were formed. Thus, safflower was capable of producing lateral roots in the trifluralin-treated soil while cotton was not.

Using snap beans (*Phaseolus vulgaris* L.) and soybeans, Struckmeyer et al. (1976) studied the effects of four dinitroaniline herbicides on the structure of the stem at the soil surface. Cellular abnormalities in the swollen stem area of treated plants included thinner walled cells, elongated xylem elements, and hypertrophy and hyperplasia of cells. While cellular injury was more severe in snap beans, the type of cellular injury was fairly similar with both plant species. Pendimethalin at 0.8 kg/ha, 1.7 kg/ha, and 3.4 kg/ha resulted in the greatest injury to both plant species tested while trifluralin caused little cellular injury even at 1.7 kg/ha.

Other soil-applied herbicides have been studied for their effects activity by arresting cell elongation or expansion, with mitotic damage being considered of secondary importance (Banting, 1970). In studies with barnyardgrass, Dawson (1963) found that EPTC affected the arrangement of mesophyll cells in leaves as well as the arrangement of chloroplasts within the cells. In the swollen coleoptilar node region, EPTC did not result in cell proliferation or cell swelling but caused an outward folding of the coleoptile around the node.

Thus, it has been shown that the injury symptoms associated with treatments of dinitroaniline and thiocarbamate herbicides are quite different. On the one hand, with the dinitroanilines, the chemicals appear to cause swelling of affected tissue as well as disruption of normal mitotic activity. On the other hand, the thiocarbamate herbicides such as triallate and EPTC appear to suppress cellular elongation or expansion with some swelling occurring at the site of uptake.

## Factors Affecting Performance of Soil-Applied Herbicides

The performance of soil-applied herbicides will depend greatly on their response to the numerous factors that influence the soil environment. Some of these factors include soil type, organic matter content, soil moisture, and soil temperature. This section of the Literature Review will discuss some of the effects of soil temperature, soil moisture, soil type, and time of application on performance of soil-applied herbicides.

### Soil Temperature

Studies with trifluralin have shown that soil temperature may influence its activity on susceptible plant species (Rahman, 1973; Mulder and Nalewaja, 1978; Darwent, 1980). Rahman (1973) conducted studies to evaluate the effects of temperature on the phytotoxicity of trifluralin to wheat, oats, and green foxtail. Oats and green foxtail were highly susceptible to trifluralin at all temperature regimes tested. However, wheat seeded to a depth of 6.3 cm showed less tolerance to trifluralin at a 32/16° C (day/night) regime than at a 16/16° C regime. Increased volatilization of trifluralin was suggested as a possible cause for the greater injury of wheat at the higher temperature regime. Furthermore, the injury was seen only when the wheat was seeded to a depth of 6.3 cm and not when it was seeded at 2.5 cm, suggesting that the increased time to emerge from the deeper seeding may be a contributing factor. The temperatures used in his studies may occur under field conditions, especially with late seedings and it was suggested that trifluralin could injure wheat seedlings in areas where high temperatures exist between the time of seeding and seedling emergence.

Experiments conducted in North Dakota showed that trifluralin toxicity to barley was not significantly affected by increasing the temperature from 10° C to 24° C. However, phytotoxicity tended to increase as temperatures increased when higher rates (2.0 kg/ha) of trifluralin were used (Mulder and Nalewaja, 1978). Moyer (1979) found that soil temperature had no significant effect on trifluralin activity and could not explain the variation in trifluralin dosages required to bring about a 90% reduction in fresh weight of wild oats ($GR_{90}$) on different soils. In his studies, soil organic matter content was the major factor affecting variability in trifluralin $GR_{90}$.

Darwent (1980) found that low soil temperatures were not responsible for poor wild oat control occasionally observed in early spring following fall-applications of trifluralin. In controlled environment studies, he found that the best level of wild oat control was achieved at 4° C, while at higher temperatures wild oats were more resistant to injury. Darwent suggested the slow growth rate of wild oats at 4° C was partially responsible for the increased activity of trifluralin, and suggested that the rate of shoot growth and the length of exposure to trifluralin vapours are closely linked. The findings of Darwent were similar to the results obtained by Pritchard (1976) in earlier studies where trifluralin was found to have more activity on wild oat roots at 4° C than at higher temperatures. Of interest in Pritchard's work is the fact that dinitramine showed less activity on wild oats at 4° C than trifluralin, but at 8° C dinitramine was more toxic.

Studies with EPTC (Mulder and Nalewaja, 1978) and triallate (Hamblin, 1977) have shown that soil temperature may affect their field performance. Hamblin (1977) suggested that cool temperatures may reduce the activity of triallate on wild oats. At low temperatures, EPTC enhanced sugarbeet shoot dry matter production while at high temperatures, the chemical reduced shoot dry matter accumulation (Mulder and Nalewaja, 1978). The difference in effects was attributed to increased volatility of EPTC at higher temperatures, resulting in it being more injurious.

From the studies reported here, it does not appear that soil temperature by itself plays a major role in affecting the performance of soil-applied herbicides. However, its influence on plant growth rate, volatility of the herbicide, and herbicide adsorption will determine how plants will respond to the chemicals under field conditions.

Soil Moisture

Soil moisture can be quite important in determining the effectiveness of soil-applied herbicides (Walker, 1970). The amount of moisture in the top 5 cm to 10 cm of the soil is probably the most important because this is the area where many soil-applied herbicides are present. At the same time, this is the region of the soil where the greatest fluctuation in moisture content occurs. Fluctuations in moisture content may affect the performance of soil-applied herbicides as changes occur in the amount of herbicide available for plant uptake.

Banting (1967) found that diallate effectively controlled wild oats in a heavy clay soil when soil moisture content was 15% (about 5% below the wilting point) which was well below field capacity (about 40%). Furthermore, he found that under dry conditions, diallate and triallate persisted much longer than under moist conditions. Hance et al.(1973) also reported more rapid volatilization of triallate from moist soil than from dry soil, which may explain the extended persistence under dry conditions.

In Manitoba, Hamblin (1977) found that on a sandy loam soil, the activity of triallate on wild oats increased as the gravimetric moisture content (G.M.C.) increased from 2% to 5%. Maximum activity of triallate on the soil was between 5% and 10% G.M.C. which is well below field capacity (25% G.M.C.). In fact, activity was found to be reduced when the soil was held at field capacity. Hamblin (1977) noted that under very dry soil conditions or very moist soil conditions, the activity of triallate may be reduced.

Studies with EPTC showed that large losses of the herbicide occurred if it was applied to moist soil (Gray and Weierich, 1965).

Within 15 minutes of application, 44% of the applied EPTC disappeared from wet soil while 20% was lost from dry soil. With losses of this magnitude, performance of EPTC was greatly affected. These researchers recommended rapid incorporation of EPTC to at least 5 cm to 7.5 cm is necessary to prevent large losses from occurring.

Studies with trifluralin have indicated that soil moisture levels may affect its performance. Using a silt loam soil, Friesen and Bowren (1973) found that on a very dry soil (less than 5% moisture content) trifluralin activity on wild oats was seriously reduced. However, at soil moisture contents above the wilting point (17.0%) and approaching field capacity, trifluralin effectively controlled wild oats. At moisture contents slightly below the wilting point, trifluralin activity was only slightly reduced. Moyer (1979) concluded from his studies on the effects of soil organic matter, soil moisture, and temperature on trifluralin activity on wild oats that trifluralin efficacy was primarily related to soil organic matter. However, he noted that the inclusion of soil moisture content improved his multiple regression model for predicting $GR_{90}$ values for trifluralin. The relationship between soil moisture content and $GR_{90}$ was similar on the four soil types studied in that $GR_{90}$ values dropped as the soil approached 50% field capacity and rose as percentage field capacity was increased. This was explained on the basis of increased adsorption at low moisture levels and reduced trifluralin vapour diffusion at high moisture contents.

Comparing several dinitroaniline herbicides including trifluralin and dinitramine, Jacques and Harvey (1979) found little difference between herbicide toxicity in soil at 55% field capacity or at 100% field capacity. When herbicide rates were around 0.25 ppmw, they were more effective at the higher moisture content but the difference was only slight.

The effects of soil moisture content on soil-applied herbicide performance is likely related to the amount of herbicide available to the plant as suggested by Walker (1970). He suggested that soil moisture affects three factors which would influence performance. These included bringing the herbicide into solution, redistribution of the herbicide in the soil, and a direct effect on herbicide availability to plants. With herbicides such as trifluralin and triallate which have vapour activity as noted previously, soil moisture probably influences their performance primarily through its effect on altering the availability for plant uptake.

Soil Type and Organic Matter Content

Soil type has been shown to influence the bioactivity and performance of soil-applied herbicides (Rahman, 1973; Grover et al., 1978; Pritchard and Stobbe, 1980). Studies with several Saskatchewan soils indicated considerable differences between triallate and trifluralin in dosages required to inhibit oat seedling growth by 50% ($GR_{50}$) (Grover et al., 1978). While trifluralin showed greater adsorption to soil, it required about half the application rate of triallate to result in a similar 50% growth reduction. For each herbicide, the $GR_{50}$ values varied significantly for the different soil types. Soil organic matter content and k values (relative adsorption to soil colloids) were good indicators of the relative bioactivity in the different soils. Other studies with Saskatchewan soils (Rahman, 1973) indicated that trifluralin phytotoxicity to wheat and green foxtail increased with decreasing organic matter content.

In studies done in Manitoba, Pritchard and Stobbe (1980) found that the phytotoxicities of dinitramine and trifluralin decreased with increasing organic matter content. They also noted that based on $ED_{50}$ (similar to $GR_{50}$) values, dinitramine was more phytotoxic than trifluralin to oats and sorghum, except to oats on a sandy loam soil. Other work in Manitoba showed that much less applied or residual trifluralin was required on an Almasippi loamy sand (organic matter 2.9%) than on a Red River clay (organic matter 8.8%) to achieve similar levels of wild oat control (Webster et al., 1978).

Placement Into the Soil

The physical placement of soil-applied herbicides will determine their activity in the soil. Gray and Weierich (1965) showed that incorporation of EPTC shortly after application is essential to prevent large herbicide losses from occurring through volatilization which would be detrimental to its activity.

Early work with diallate and triallate in Western Canada has shown that they can be selectively placed into the soil so that adequate wild oat control is achieved with little injury to wheat (Friesen et al., 1962; Molberg et al., 1964). This practice can be achieved by seeding wheat to a depth of 7.5 cm, applying the herbicide and incorporating it shallowly with harrows. The incorporation distributes the chemical into the surface layer of soil and minimizes loss by volatilization (Banting, 1967; Molberg et al., 1964; Beestman and Deming, 1976).

Research with trifluralin in Western Canada indicated that field practices could be modified to allow its use in several agronomic crops (Rahman and Ashford, 1970; Friesen and Bowren, 1973; Chow, 1976). Placement of wheat seeds below a layer of trifluralin-treated soil provided good wheat tolerance and selective control of green foxtail

(Rahman and Ashford, 1970). The selective placement can be achieved in a similar fashion to the placement of triallate for wild oat control in wheat. Again, the incorporation is necessary to prevent losses of trifluralin through volatilization (Bardsley et al., 1968).

Other work has shown that trifluralin is suitable for wild oat and green foxtail control in rapeseed (Friesen and Bowren, 1972; Chow, 1976). Friesen and Bowren (1973) found that incorporation of trifluralin to a depth of 7.5 cm did not affect wild oat control or rapeseed tolerance. However, activity on wild oats was reduced by high organic matter or by incorporating the herbicide to depths below 7.5 cm. Chow (1976) determined that trifluralin and dinitramine applications incorporated into the soil with discs gave better control of green foxtail and wild oats than did incorporation with harrows. It was also noted that in some instances, dinitramine thinned stands and reduced yields of rapeseed.

## Timing of Soil-Applied Herbicide Applications

In studies on wild oat control in rapeseed, Friesen and Bowren (1973) reported that fall applications of trifluralin at 1.12 kg/ha gave control equivalent to a similar spring treatment. When the rate was decreased to 0.84 kg/ha, wild oat control was not satisfactory with either the fall or spring applications. Under dry spring conditions, fall applications significantly improved rapeseed seed yields compared to the spring treatment. The difference was attributed to improved soil moisture conditions in the spring from fall treatments since less spring tillage was required and a better stand was established.

In North Dakota, studies have been done to compare the efficacy of granular (G) and emulsifiable concentrate (EC) formulations of triallate in controlling wild oats following a fall or spring application (Miller and Nalewaja, 1980). Wild oat control was consistently better from the fall application of G triallate than from all other treatments. When comparing spring treatments, the EC formulation resulted in better control than the granular. It was suggested that the fall-applied granules were more effective than the other treatments because less herbicide was lost through volatilization. In contrast, the EC formulation of triallate showed more activity with the spring application because the chemical was more evenly distributed in the soil. Earlier studies conducted in Manitoba had shown little difference between the EC and G formulations of triallate when applied in the fall or in the spring (Hamblin, 1977).

In field experiments comparing fall and spring applications of trifluralin and metribuzin [4-amino-6-tert-butyl-3-(methylthio)-as-triazine-5(4H)-one] in fababeans, Betts and Morrison (1979) found that trifluralin effectively controlled green foxtail and wild oats when applied in the fall or in the spring. However, fababean seed yields were generally higher in the fall-treated plots even though weed densities were similar to those found in spring-treated plots. Less crop injury following fall applications of trifluralin and metribuzin was cited as a possible reason for improved seed yields.

In order for fall applications of soil-applied herbicides to be of practical use, sufficient chemical must be present in the spring to control seedling weeds. In studies conducted in Saskatchewan, carryover of trifluralin, dinitramine, and triallate was shown to be quite variable on three different soil types (Smith, 1975). For example, triallate applied in October at 1.7 kg/ha showed between 45% and 65% loss prior to May sampling. Losses of trifluralin over the same period varied between 30% and 70% of the applied chemical. However, both of these herbicides have been shown to result in excellent weed control when applied in the fall (Friesen and Bowren, 1973; Betts and Morrison, 1979; Miller and Nalewaja, 1980).

## Persistence of Soil-Applied Herbicides

The persistence of soil-applied herbicides governs the duration of their biological effectiveness in controlling weeds. While it would be desirable for the herbicide to provide complete weed control throughout the entire growing season, carryover of phytotoxic residues to subsequent growing seasons may limit the choice of available crops. Ideally, soil-applied herbicides must persist long enough to effectively control weed growth well into the growing season, but they must not pose carryover problems.

Much of the research on persistence of soil-applied herbicides has centered around the dinitroaniline herbicides, especially trifluralin. A review article by Helling (1976) covers the behavior and fate of dinitroaniline herbicides in the soil. Much of the literature summarized in the review suggests that volatilization, photodecomposition, and chemical degradation are the major means by which dissipation of dinitroaniline herbicides occurs. Factors such as soil type (Rahman, 1973), rate of application (Messersmith *et al*., 1971), and climatic factors (Smith and Hayden, 1976) have all been shown to influence persistence.

Volatilization

Vapour losses may be an important means of herbicide dissipation and significantly influence the extent of persistence in the soil. While volatility of a herbicide may influence persistence, at the same time, uptake of vapours may be an important mode of entry into plants (Swann and Behrens, 1972).

Considerable research has shown that the dinitroanilines are relatively volatile herbicides (Bardsley et al., 1968; Parochetti et al., 1976; and others). Parochetti et al. (1976) determined that trifluralin was very volatile while dinitramine and pendimethalin were moderately volatile. Within 3 hours at 30° C, 4% of the applied trifluralin was lost from a sandy soil. The losses for dinitramine and pendimethalin under similar conditions were 1.5% and 0.5%, respectively. These researchers also found that increasing the temperature and decreasing the moisture content of the soil increased the rate of volatilization, although this occurred only at moisture contents above field capacity.

Under field conditions, total seasonal loss of trifluralin into the air was 25.9% of the applied chemical (White et al., 1977). This figure included a 3.5% loss of the applied chemical during application and a 22.4% loss of the applied chemical by volatilization during the 120 days following treatment. However, later studies by Hollingsworth (1980) indicated that less than 0.5% of the applied trifluralin was detected as vapours during a 4 month period. These large discrepancies between the amount of trifluralin lost through volatilization are difficult to explain. Some of the differences may be accounted for by the fact that Hollingsworth did not begin sampling until several hours after application. In addition, the study of White et al. (1977) was conducted with a sandy soil while Hollingsworth (1980) used a silt loam soil which could influence the rates of volatilization through differences in the surface area of the soil.

Other researchers have shown that vapour loss of trifluralin is proportional to its concentration in the soil (Bardsley et al., 1968). These workers also determined that incorporation into the soil greatly reduced the amount of vapour loss.

Harper et al. (1976) studied the effects of microclimate on trifluralin volatilization and determined vapour loss exhibited a diurnal pattern, with little herbicide loss occurring during the day and increased losses occurring during the night. They attributed the differences to changes in surface soil water content. High evaporative demand increased trifluralin adsorption during the relatively dry daytime period and increased volatilization occurred during the nighttime when evaporative demand decreased and surface soil water content increased. Apparently, adsorption to the soil particles upon drying was reversible, since rapid increases in volatilization were noted whenever the surface soil was moistened by dew or rainfall to above three molecular layers of water (about 2% gravimetric moisture content).

Studies with other soil-applied herbicides have indicated that the rate of volatilization can be an influencing factor on persistence (Fang et al., 1961; Gray and Weierich, 1965; Hance et al., 1973). Fang et al. (1961) showed losses of EPTC vapour to be dependent upon soil moisture levels and soil type. Later work indicated immediate incorporation of EPTC could prevent large losses of the chemical from occurring (Gray and Weierich, 1965). Volatility of triallate increased with increasing soil moisture content and was generally greater from the emulsifiable concentrate formulation than from the granular formulation (Hance et al., 1973). From wet soil surfaces, it took 3 days for a 50%

loss of emulsifiable concentrate to occur while the period was extended to 8.5 days for the same amount of granular triallate to be lost. On dry soil, triallate was much more persistent.

Photodecomposition. Persistence of some of the dinitroaniline herbicides has been shown to be affected by photodecomposition (Wright and Warren, 1965; Parochetti and Dec, 1978). Parochetti and Dec (1978) reported that 18.4% of the applied trifluralin and 72.3% of the applied dinitramine were photodecomposed after exposure to sunlight for 7 days. In his review on dinitroaniline herbicides in the soil, Helling (1976) noted that enhancement of trifluralin activity by incorporation into the soil may be the result of decreased photodecomposition along with decreased volatilization. With trifluralin, photodecomposition involved the processes of dealkylation and nitro reduction (Leitis and Crosby, 1974). They also suggested that many of the metabolites would be further transformed in the environment.

Degradation. While the above discussion points out that photodecomposition is one of the many degradative processes which may affect herbicide persistence, other work has shown that dinitroanilines undergo degradation in the soil (Helling, 1976). Generally, dinitroanilines appear to degrade in the soil by oxidative and reductive pathways. Oxidation is classically associated with aerobic soils and involves a series of dealkylation steps. The reductive pathway is associated with anaerobic soils and involves reduction of the nitro groups. Under field conditions, both processes are likely to occur.

Zimdahl and Gwynn (1977) noted that the extent of trifluralin degradation was positively correlated with soil moisture content over the range of 0% to 100% field capacity. They also found a slower rate of degradation at a low temperature (15° C) than at a high temperature (30° C). Degradation of trifluralin proceeded more slowly in a sandy loam soil than in a loam soil. The difference was attributed to higher soil microbial activity in the loam soil (Zimdahl and Gwynn, 1977).

Savage (1978) indicated that persistence of trifluralin and pendimethalin was shorter under flooded soil conditions than in a soil held at field capacity. It was suggested that both herbicides degraded more rapidly under anaerobic conditions than aerobic conditions. However, trifluralin has been shown to volatilize more readily from aqueous solution than from soil (Bardsley et al., 1968) and thus the decrease in persistence under flooded conditions may be due to increased volatilization rather than increased degradation.

Studies with dinitramine and trifluralin have indicated that microbial activity may be involved in degradation (Laanio et al., 1973; Zimdahl and Gwynn, 1977). Zimdahl and Gwynn (1977) speculated that soil bacteria may degrade dinitroaniline, whereas Laanio et al. (1973) isolated species of fungi capable of degrading trifluralin and dinitramine.

Degradation of soil-applied herbicides plays an important role in the reduction of amounts of herbicide in the soil. The more quickly a herbicide is degraded, the shorter its persistence in the soil and similarly its duration of bioactivity.

## Persistence Under Prairie Conditions

Much of the research on persistence of soil-applied herbicides, especially trifluralin and triallate, in Western Canada has been done in Saskatchewan (Smith, 1969, 1970, 1971, 1975, 1978; Smith and Hayden,

1976) with a few studies done in Manitoba (Pritchard, 1977; Webster et al., 1978; Pritchard and Stobbe, 1980). Most of these studies have dealt with residue levels found in the soil at the completion of the cropping season.

Persistence of several dinitroaniline herbicides including trifluralin and dinitramine has been studied on three Manitoba soils (Pritchard, 1977; Pritchard and Stobbe, 1980). On sandy loam and clay loam soils, trifluralin persisted to a greater extent than did dinitramine. On a clay soil, dinitramine persisted longer than trifluralin. These studies also noted that the rate of disappearance expressed as a percent of applied chemical was not affected by changes in herbicide applications rates.

Webster et al. (1978) found that trifluralin residues declined to about 47% of the applied dosage after 16 weeks on Red River clay (organic matter 8.8%, clay 73%), Gladstone clay loam (organic matter 9.2%, clay 34%), and Newdale loam (organic matter 6.8%, clay 26%) soils and to 40% of initial levels on Almasippi loamy sand (organic matter 2.9%, clay 8%) soil. However, while trifluralin residues were much the same on all soil types, bioactivity of the residues varied with the soil type and was mathematically related to clay content of the soils. It was also noted that the loss of trifluralin was best explained by first order kinetics.

Studies in Saskatchewan over a 3 year period have shown trifluralin residues from a spring application to be less than 15% on sandy loam and heavy clay soils at the end of the growing season (Smith and Hayden, 1976). However, on a silty loam soil, up to 31% of the applied trifluralin persisted through the growing season. In the same study, dinitramine residues were shown to be lower than trifluralin residues on sandy loam and silty loam soils but higher on a clay soil.

Studies on the persistence of spring-applied triallate have shown that 14% to 27% of the applied herbicide was found in the soil at the end of the growing season (Smith 1970, 1971, 1975). Smith (1971) suggested that under Saskatchewan conditions soil type may not be an important factor affecting triallate loss from the soil. It was also suggested that due to the carryover potential of triallate, care should be exercised when selecting a crop to be grown on triallate-treated soil the year after application.

Studies with fall applications of triallate, trifluralin, and dinitramine have shown that considerable herbicide loss may occur from time of application to early May (Smith, 1975). For trifluralin and dinitramine, between 30% and 70% of the applied chemical was lost prior to sampling. Losses of triallate varied from 25% to 77% of the applied chemical on a heavy clay soil to 46% to 63% on a sandy loam soil. Considerable differences in the extent of herbicide loss occurred during the two winter seasons included in the study. Under mild winter conditions, herbicide carryover to the spring following a fall application was much less. It was also noted that soil temperature and soil moisture conditions at time of application and prior to freeze-up in the fall would influence persistence as would conditions after spring thaw and prior to soil sampling.

More recent studies have shown that when triallate and trifluralin are used in combination, field persistence of either chemical is similar to that occurring when they had been applied alone (Smith, 1978). The fact that persistence of triallate and trifluralin is unaffected when used as a dual treatment is important considering that this tank mix is commonly used by farmers for wild oat and green foxtail in wheat and barley.

# CHAPTER II

## FIELD STUDIES WITH FALL AND SPRING APPLICATIONS OF SOIL-APPLIED HERBICIDES

### Introduction

In Western Canada, applying soil-applied herbicides in the fall is common practice. This approach appeals to many farmers because it means less time is spent applying and incorporating the chemicals during the busy spring seeding period. Furthermore, a fall application of a herbicide may improve the soil moisture status at seeding time compared to a spring application because with fall applications less spring tillage is required. However, soil erosion may increase during the winter months following fall incorporations which bury the crop stubble.

In order for fall applications of soil-incorporated herbicides to work satisfactorily, they must maintain their phytotoxicity to susceptible weeds. In North Dakota, Miller and Nalewaja (1980) found that control of wild oats was greater with granular triallate applied in the fall than with spring applications of either the granules or the emulsifiable concentrate (EC). The EC formulation of triallate resulted in better control of wild oats than the granules when applied in the spring. These researchers suggested that the granules were more effective following a fall application because less was lost through volatilization, and that diffusion and spring tillage for seedbed preparation improved the distribution of triallate following the fall application.

Friesen and Bowren (1973) found that fall applications of trifluralin at 1.12 kg/ha active ingredient (a.i.) resulted in wild oat control nearly equal to that of a similar spring application in rapeseed. Incorporation of spring-applied trifluralin greatly reduced rapeseed stands in two tests. Similar stand reductions were not apparent with a fall application. This difference was attributed to very dry spring conditions which affected germination of the shallow-seeded rapeseed. In the spring-treated plots extra tillage was required to properly incorporate the trifluralin and the seedbed was dried out even more, resulting in poor germination.

In a study conducted by Betts and Morrison (1979) in which fall and spring applications of trifluralin and metribuzin were used for weed control in fababeans, fall applications of both chemicals resulted in comparable weed control to the spring treatment. Furthermore, the fall application of metribuzin was less injurious to fababeans than a spring application, even though it was applied at a higher rate in the fall. When tank mixed, trifluralin and metribuzin applied in the fall resulted in higher fababean seed yield than a similar spring application and the fall treatment showed better crop tolerance and equivalent weed control compared to the spring treatment.

This study was undertaken to compare the efficacy of fall and spring applications of several soil-applied herbicides taking into account differences in both crop tolerance and levels of weed control in flax and rapeseed.

## Materials and Methods

In the fall of 1977 and 1978, field trials were established on an Almasippi very fine, sandy loam soil at the University of Manitoba research site near Graysville, Manitoba. The soil consisted of 79% sand, 7% silt, and 14% clay and had a pH of 7.6. The organic matter content was 3.7%. Each trial was arranged in a randomized complete block design with each treatment replicated four times. Individual plot size was 2.8 x 5.0 m and 2.8 x 10.0 m in 1977 and 1978, respectively. Larger plots were used in the second year of the study to facilitate improved soil incorporation of the herbicides.

Prior to establishment of the trials, the site was disced and harrowed. In the flax experiments, treatments consisted of a weedy control, a hand-weeded control, and EPTC emulsifiable concentrate (EC), both emulsifiable and granular (G) formulations of triallate, and trifluralin EC, each at three different rates (Table 1). Treatments in the rapeseed experiments consisted of a weedy control, a hand-weeded control, and EC formulations of dinitramine, pendimethalin, trifluralin, and triallate, each at three different rates, except in 1977 where triallate and trifluralin were applied at only two rates (Table 2). The higher fall-applied rates of the herbicides were included in the study to investigate uptake of herbicides by weed seeds in the soil which will be discussed in Chapter IV. Consequently, in this section, results from the high application rate will be mentioned only if they differ significantly from the commercial application rates.

All herbicides were applied in a volume of 132 L/ha using a bicycle-wheel sprayer equipped with Teejet 80015 flat-fan nozzles and operated at a forward speed of 4.8 kmph and a spray pressure of 276 kPa. All fall treatments were incorporated once with a tandem disc immediately following application. A second incorporation, parallel to the first,

Table 1. Herbicide formulations, rates, and dates of fall and spring applications in flax.

| Treatment | Formulation[a] | Rate (kg/ha) | Type of application | Dates of Application | |
|---|---|---|---|---|---|
| | | | | Year 1[b] | Year 2[b] |
| EPTC | 80% EC | 2.8 | spring | May 11/78 | May 27/79 |
| EPTC | 80% EC | 3.3 | fall | Oct. 23/77 | Nov. 1/78 |
| EPTC | 80% EC | 6.6 | fall | Oct. 23/77 | Nov. 1/78 |
| Triallate | 40% EC | 1.68 | spring | May 11/78 | May 27/79 |
| Triallate | 40% EC | 1.68 | fall | Oct. 23/77 | Nov. 1/78 |
| Triallate | 40% EC | 3.36 | fall | Oct. 23/77 | Nov. 1/78 |
| Triallate | 10% G | 1.68 | spring | May 11/78 | May 27/79 |
| Triallate | 10% G | 1.68 | fall | Oct. 23/77 | Nov. 1/78 |
| Triallate | 10% G | 3.36 | fall | Oct. 23/77 | Nov. 1/78 |
| Trifluralin | 40% EC | 0.84 | spring | May 11/78 | May 27/79 |
| Trifluralin | 40% EC | 1.12 | fall | Oct. 23/77 | Nov. 1/78 |
| Trifluralin | 40% EC | 2.24 | fall | Oct. 23/77 | Nov. 1/78 |

[a]The amount of active ingredient is expressed as a percentage of the formulation. EC = emulsifiable concentrate, G = granular.

[b]Two separate trials were established, with the fall treatments in the first trial being applied in 1977 and in the second trial in 1978.

Table 2. Herbicide formulations, rates, and dates of fall and spring applications in rapeseed.

| Treatment | Formulation[a] | Rate (kg/ha) | Type of application | Dates of Application | |
|---|---|---|---|---|---|
| | | | | Year 1[b] | Year 2[b] |
| Dinitramine | 24% EC | 0.74 | spring | May 11/78 | May 27/79 |
| Dinitramine | 24% EC | 0.84 | fall | Oct. 22/77 | Nov. 1/78 |
| Dinitramine | 24% EC | 1.68 | fall | Oct. 22/77 | Nov. 1/78 |
| Trifluralin | 40% EC | 0.84 | spring | May 11/78 | May 27/79 |
| Trifluralin | 40% EC | 1.12 | fall | Oct. 22/77 | Nov. 1/78 |
| Trifluralin | 40% EC | 2.24 | fall | -- | Nov. 1/78 |
| Pendimethalin | 44% EC | 2.2 | spring | May 11/78 | May 27/79 |
| Pendimethalin | 44% EC | 3.0 | fall | Oct. 22/77 | Nov. 1/78 |
| Pendimethalin | 44% EC | 4.5 | fall | Oct. 22/77 | Nov. 1/78 |
| Triallate | 40% EC | 1.68 | spring | May 11/78 | May 27/79 |
| Triallate | 40% EC | 1.68 | fall | Oct. 22/77 | Nov. 1/78 |
| Triallate | 40% EC | 3.36 | fall | -- | Nov. 1/78 |

[a]The amount of active ingredient is expressed as a percentage of the formulation. EC = emulsifiable concentrate.

[b]Two separate trials were established, with the fall treatments in the first trial being applied in 1977 and in the second trial in 1978.

but in the opposite direction, was done in the spring prior to seeding. Spring treatments of each herbicide were incorporated twice with the tandem disc following application. Trifluralin, dinitramine, and pendimethalin were incorporated with the implement cutting to a depth of 10 cm, while for both formulations of triallate and EPTC, the disc was set to cut to a depth of 7.5 and 15 cm, respectively.

Prior to the second incorporation of all treatments, fertilizer was broadcast onto the soil surface at levels recommended by the Manitoba Soil Testing Lab based on actual test results. In 1978, 121 kg/ha of 34-0-0 (ammonium nitrate) were broadcast and in 1979, 158 kg/ha of 27-27-0 (urea ammonium phosphate) were applied to the flax and rapeseed experiments. In addition, 41 kg/ha of 11-55-0 (ammonium phosphate) were applied with the rapeseed and prior to seeding the flax in the 1978 trials.

Flax was seeded to a depth of 2 cm at a seeding rate of 40.7 kg/ha with an International double-disc press drill on May 18, 1978 and on June 5, 1979. Rapeseed was seeded to a depth of 2 cm with the same implement on May 17, 1978 and June 5, 1979 at seeding rates of 6.4 and 6.0 kg/ha, respectively. Prior to seeding, the seedbed was firmed with the packers on the press drill.

In 1978, the rapeseed was treated with Gammasan + (lindane/captan/benomyl 25:5:3) at 31 g product per kg of seed for control of seedling diseases and flea beetles. Additional treatments of malathion on May 27 and June 3, 1978 at 562 ml product per ha were used to control the flea beetles. Benlate T (benomyl/thiram 1:1) at 12.5 g product per kg of seed and Furadan 5 G (carbofuran) at 5 kg product per 6 kg of seed were used as seed treatments for control of seedling diseases and flea beetles in rapeseed in 1979. No seed treatments were used in the flax trials.

In both years of the study, the flax trial was given an overall treatment of Buctril M (bromoxynil/MCPA 1:1) at 0.56 kg/ha active ingredient (a.i.) for control of broadleaf weeds. Benazolin at 0.7 kg/ha a.i. was applied to the rapeseed experiment in both years for control of wild mustard and suppression of other broadleaf weeds such as wild buckwheat, lambsquarters, and redroot pigweed.

Crop and weed counts were taken about 4 weeks after seeding using a 0.0625 $m^2$ quadrate placed randomly at two locations within each plot. Values were then expressed as plants/$m^2$. Visual assessments based on a 0-9 scale adopted by Expert Committee on Weeds (Western Section) (Appendix Table 1) were used to assess crop tolerance and weed control. In assessing crop tolerance, 0 indicates complete kill of the crop and 9 means complete crop tolerance. For weed control, 0 indicates no visible effects on the weeds and 9 means complete control of the weed.

In 1978, seed yields in the flax and rapeseed experiments were determined by hand harvesting a 2 $m^2$ area within each plot and threshing the samples using a Vogel stationary thresher. The flax experiment in 1979 was harvested with a Hege plot combine taking a 12 $m^2$ sample from each plot. A 10 $m^2$ sample was hand harvested from the rapeseed experiment in the second year of the study and threshed using a Vogel stationary thresher. Following seed cleaning, plot yields were determined and expressed on a g/$m^2$ basis.

# Results

## Flax Experiments

Weed densities and visual assessments in the flax experiments are reported in Tables 3 and 5. EPTC treatments resulted in variable control of green foxtail in the 2 years of the study. The spring treatment at 2.8 kg/ha a.i. reduced levels of green foxtail in flax but this decrease was only significant in 1978. Visual assessments taken late in the season indicated that control was still unacceptable because a large number of plants were producing seed. EPTC applied in the fall at 3.3 kg/ha a.i. resulted in poor control of green foxtail during both years of the study. The spring application of EPTC resulted in satisfactory control of wild oats in 1978 (Table 3). Wild oats densities were not determined in 1979 because of low levels of infestation.

Triallate treatments in 1978 had little effect on green foxtail populations while giving excellent control of wild oats. Fall applications of granular or EC formulations of triallate at 1.68 kg/ha a.i. resulted in reduced green foxtail infestations. In 1979, these same two treatments significantly reduced green foxtail populations compared to the untreated control and in the case of granular triallate, the fall application had significantly fewer green foxtail plants than the spring treatment.

All three trifluralin treatments significantly reduced densities of green foxtail and wild oats (Table 3). The fall applications tended to result in better control of green foxtail than the spring treatment in both years of the study but the difference was only statistically significant with the higher fall-applied rate in 1979.

Tolerance and yield response of flax to the soil-applied herbi-

Table 3. The effect of fall and spring applications of several soil-applied herbicides on control of green foxtail and wild oats in flax, 1978.

| Treatment | Rate | Time of application | Green Foxtail Control Ratings[a] June 18 | Green Foxtail Control Ratings[a] July 9 | Green Foxtail Plant Density[b] | Wild Oats Control Ratings[a] June 18 | Wild Oats Control Ratings[a] July 9 | Wild Oats Plant Density[b] |
|---|---|---|---|---|---|---|---|---|
| | (kg/ha) | | | | (plants/m$^2$) | | | (plants/m$^2$) |
| Untreated | | | 0 | 0 | 123 a | 0 | 0 | 58 a |
| Handweeded | | | 9 | 9 | 0 d | 9 | 9 | 0 b |
| EPTC | 2.8 | spring | 5 | 5 | 24 bcd | 8 | 8 | 4 b |
| EPTC | 3.3 | fall | 4 | 3 | 88 a | 7 | 6 | 6 b |
| EPTC | 6.6 | fall | 4 | 3 | 109 a | 7 | 7 | 10 b |
| Triallate EC | 1.68 | spring | 0 | 0 | 116 a | 9 | 9 | 0 b |
| Triallate EC | 1.68 | fall | 3 | 2 | 98 a | 8 | 8 | 2 b |
| Triallate EC | 3.34 | fall | 0 | 0 | 86 a | 9 | 9 | 0 b |
| Triallate G | 1.68 | spring | 0 | 0 | 114 a | 8 | 8 | 6 b |
| Triallate G | 1.68 | fall | 3 | 2 | 62 abc | 8 | 8 | 2 b |
| Triallate G | 1.68 | fall | 2 | 1 | 72 ab | 8 | 8 | 2 b |
| Trifluralin | 0.84 | spring | 8 | 8 | 6 cd | 6 | 6 | 12 b |
| Trifluralin | 1.12 | fall | 9 | 8 | 2 cd | 6 | 6 | 8 b |
| Trifluralin | 2.24 | fall | 9 | 9 | 0 d | 8 | 7 | 2 b |

[a] Weed control was assessed on a 0-9 scale where 0 = no effect on the weed and 9 = complete control of the weed.

[b] Weed densities followed by the same letter within a column are not significantly different at the 5% level according to Duncan's Multiple Range Test.

Table 4. The effect of fall and spring applications of several soil-applied herbicides on crop tolerance, crop density, and seed yield of flax, 1978.

| Treatment | Rate | Time of application | Tolerance Ratings[a] June 18 | Tolerance Ratings[a] July 9 | Crop density[b] | Seed yield[b] |
|---|---|---|---|---|---|---|
| | (kg/ha) | | | | (plants/m²) | (g/m²) |
| Untreated | | | 9 | 9 | 320 ab | 67 f |
| Handweeded | | | 9 | 9 | 308 ab | 133 a |
| EPTC | 2.8 | spring | 7 | 6 | 170 cde | 111 abcd |
| EPTC | 3.3 | fall | 8 | 8 | 306 ab | 80 def |
| EPTC | 6.6 | fall | 7 | 7 | 278 abc | 99 bcde |
| Triallate EC | 1.68 | spring | 7 | 7 | 170 cde | 93 cdef |
| Triallate EC | 1.68 | fall | 8 | 8 | 332 ab | 111 abcd |
| Triallate EC | 3.34 | fall | 7 | 8 | 234 abc | 103 abcd |
| Triallate G | 1.68 | spring | 8 | 8 | 216 bcde | 101 bcde |
| Triallate G | 1.68 | fall | 8 | 8 | 348 a | 119 abc |
| Triallate G | 1.68 | fall | 7 | 8 | 230 bcd | 102 abcde |
| Trifluralin | 0.84 | spring | 4 | 5 | 70 ef | 102 abcde |
| Trifluralin | 1.12 | fall | 6 | 6 | 114 def | 127 ab |
| Trifluralin | 2.24 | fall | 3 | 4 | 22 f | 71 ef |

[a]Crop tolerance was assessed on a 0-9 scale where 0 = complete kill and 9 = complete tolerance.

[b]Crop density and seed yield followed by the same letter within a column are not significantly different at the 5% level according to Duncan's Multiple Range Test.

Table 5. Effects of fall and spring applications of several soil-applied herbicides on green foxtail and flax, 1979.

| Treatment | Rate | Time of application | Green Foxtail: Control Ratings[a] July 11 | Green Foxtail: Control Ratings[a] Aug. 11 | Green Foxtail: Density[b] | Flax: Control Ratings[a] July 11 | Flax: Control Ratings[a] Aug. 11 | Flax: Density[b] | Flax: Seed yield[b] |
|---|---|---|---|---|---|---|---|---|---|
| | (kg/ha) | | | | (plants/m$^2$) | | | (plants/m$^2$) | (g/m$^2$) |
| Untreated | | | 0 | 0 | 76 ab | 9 | 9 | 298 a | 102 e |
| Handweeded | | | 9 | 9 | 0 d | 9 | 9 | 310 a | 162 a |
| EPTC | 2.8 | spring | 6 | 7 | 40 bcd | 7 | 8 | 196 de | 134 abcde |
| EPTC | 3.3 | fall | 4 | 2 | 74 ab | 8 | 8 | 292 a | 111 cde |
| EPTC | 6.6 | fall | 5 | 3 | 30 cd | 7 | 8 | 250 b | 128 bcde |
| Triallate EC | 1.68 | spring | 4 | 5 | 58 abc | 9 | 9 | 320 a | 136 abcd |
| Triallate EC | 1.68 | fall | 4 | 5 | 26 cd | 8 | 9 | 296 a | 154 ab |
| Triallate EC | 3.34 | fall | 6 | 6 | 22 cd | 8 | 9 | 292 a | 136 abcd |
| Triallate G | 1.68 | spring | 3 | 4 | 92 a | 8 | 8 | 206 cd | 132 abcde |
| Triallate G | 1.68 | fall | 3 | 6 | 30 cd | 9 | 9 | 308 a | 162 a |
| Triallate G | 1.68 | fall | 7 | 6 | 14 cd | 7 | 8 | 195 de | 146 ab |
| Trifluralin | 0.84 | spring | 7 | 7 | 30 cd | 7 | 7 | 244 b | 143 abc |
| Trifluralin | 1.12 | fall | 8 | 8 | 6 d | 7 | 8 | 240 bc | 153 ab |
| Trifluralin | 2.24 | fall | 9 | 9 | 0 d | 5 | 5 | 168 e | 104 de |

[a]Weed control and crop tolerance were assessed on a 0-9 scale where 0 = complete kill of the crop and no effect on the weed and 9 = complete tolerance of the crop and complete control of the weed.

[b]Stand density and seed yield followed by the same letter within a column are not significantly different at the 5% level according to Duncan's Multiple Range Test.

cides for 1978 and 1979 are shown in Tables 4 and 5, respectively. In both years, spring-applied EPTC significantly reduced flax stand density, although significant yield reductions did not occur. EPTC applied in the fall at 3.3 kg/ha a.i. showed better crop tolerance than a spring application, but seed yields were significantly lower than in the hand-weeded control.

Flax seed yields were lower than the hand-weeded control for all triallate treatments but this difference was only significant for spring-applied granular and EC formulations in 1978, where green foxtail populations were equivalent to the untreated, weedy control. Flax stand density was significantly reduced by the spring EC formulations of triallate in 1978 and by the granular fall application in 1979. The reduction in stand density does not always parallel reductions in flax seed yield for the triallate treatments.

In both years, all trifluralin treatments significantly reduced flax densities compared to either the untreated or the hand-weeded controls (Tables 4 and 5). However, the reduction did not significantly affect seed yields when the chemical was applied at commercially recommended rates in either the fall (1.12 kg/ha a.i.) or the spring (0.84 kg/ha a.i.). Fall application of trifluralin at 1.12 kg/ha a.i. resulted in higher yields than the spring application in both years but the differences were not statistically significant. When applied at twice the recommended rate, the fall trifluralin treatment significantly reduced flax seed yields compared to the hand-weeded control during both years of the study.

Of the three herbicides tested in the flax experiments, trifluralin resulted in the best control of green foxtail. Triallate treatments controlled wild oats to the greatest extent when this weed was present in the 1978 field trials. Of the triallate treatments, the granular spring application resulted in the poorest level of wild oat control although control was not significantly different from the other triallate applications. Commercial application rates of fall or spring-applied trifluralin and spring-applied EPTC significantly reduced flax stand densities but did not significantly affect seed yields, compared to the hand-weeded control.

Rapeseed Experiments

The levels of weed control from several soil-applied herbicides used in rapeseed are given in Tables 6 and 8. Dinitramine treatments resulted in variable control of green foxtail in the 2 years of the study. In both years, commercial application rates of dinitramine applied either in the fall (0.84 kg/ha a.i.) or spring (0.74 kg/ha a.i.) significantly reduced green foxtail densities compared to the weedy control. However, the level of control was much less in 1979 than in 1978 with these treatments. Control of wild oats was excellent with all dinitramine treatments in 1978.

Fall and spring applications of trifluralin resulted in excellent control of green foxtail in rapeseed in 1978 (Table 6). In the second year of the study, green foxtail control by trifluralin treatments was less than in the previous year (Tables 6 and 8). While foxtail populations in the trifluralin-treated plots were significantly lower than in the untreated control in 1979, the level of control was less than that seen in the flax experiment during the same season.

In both years, pendimethalin treatments resulted in excellent control of green foxtail although the spring application at 2.2 kg/ha

Table 6. The effect of fall and spring applications of several soil-applied herbicides on control of green foxtail and wild oats in rapeseed, 1978.

| Treatment | Rate | Time of application | Green Foxtail Control Ratings[a] June 19 | Green Foxtail Control Ratings[a] July 9 | Green Foxtail Density[b] | Wild Oats Control Ratings[a] June 19 | Wild Oats Control Ratings[a] July 9 | Wild Oats Density[b] |
|---|---|---|---|---|---|---|---|---|
| | (kg/ha) | | | | (plants/$m^2$) | | | (plants/$m^2$) |
| Untreated | | | 0 | 0 | 68 a | 0 | 0 | 46 a |
| Handweeded | | | 9 | 9 | 0 c | 9 | 9 | 0 b |
| Dinitramine | 0.74 | spring | 7 | 7 | 26 bc | 8 | 7 | 4 b |
| Dinitramine | 0.84 | fall | 7 | 7 | 1 b | 7 | 6 | 4 b |
| Dinitramine | 1.68 | fall | 8 | 7 | 0 c | 8 | 8 | 4 b |
| Trifluralin | 0.84 | spring | 8 | 8 | 0 c | 8 | 7 | 10 b |
| Trifluralin | 1.12 | fall | 9 | 9 | 4 c | 7 | 8 | 10 b |
| Pendimethalin | 2.2 | spring | 9 | 8 | 0 c | 8 | 8 | 4 b |
| Pendimethalin | 3.0 | fall | 8 | 9 | 2 c | 8 | 8 | 2 b |
| Pendimethalin | 4.5 | fall | 9 | 8 | 0 c | 8 | 8 | 4 b |
| Triallate EC | 1.68 | spring | 0 | 1 | 112 a | 9 | 9 | 0 b |
| Triallate EC | 1.68 | fall | 0 | 2 | 74 a | 8 | 8 | 6 b |

[a]Weed control was assessed on 0-9 scale where 0 = no effect and 9 = complete control of the weed.

[b]Weed density followed by the same letter within a column are not significantly different at the 5% level according to Duncan's Multiple Range Test.

Table 7. The effect of fall and spring applications of several soil-applied herbicides on crop tolerance, crop density, and seed yield of rapeseed, 1978.

| Treatment | Rate | Time of application | Tolerance Ratings[a] | | Crop density[b] | Seed yield[b] |
|---|---|---|---|---|---|---|
| | | | June 18 | July 9 | | |
| | (kg/ha) | | | | (plants/$m^2$) | (g/$m^2$) |
| Untreated | | | 9 | 9 | 100 a | 70 bcd |
| Handweeded | | | 9 | 9 | 104 a | 110 a |
| Dinitramine | 0.74 | spring | 6 | 7 | 18 b | 84 abcd |
| Dinitramine | 0.84 | fall | 7 | 7 | 30 b | 93 abc |
| Dinitramine | 1.68 | fall | 5 | 6 | 8 b | 88 abcd |
| Trifluralin | 0.84 | spring | 8 | 8 | 80 a | 117 a |
| Trifluralin | 1.12 | fall | 9 | 9 | 96 a | 110 a |
| Pendimethalin | 2.2 | spring | 5 | 7 | 20 b | 69 cd |
| Pendimethalin | 3.0 | fall | 5 | 7 | 26 b | 94 ab |
| Pendimethalin | 4.5 | fall | 2 | 5 | 10 b | 56 d |
| Triallate EC | 1.68 | spring | 8 | 8 | 74 a | 88 abcd |
| Triallate EC | 1.68 | fall | 9 | 9 | 94 a | 83 abcd |

[a]Crop tolerance was assessed on a 0-9 scale where 0 = complete kill of the crop and 9 - complete tolerance.

[b]Crop density and seed yield followed by the same letter within a column are not significantly different at the 5% level according to Duncan's Multiple Range Test.

Table 8. Effects of fall and spring applications of several soil-applied herbicides on green foxtail and rapeseed, 1979.

| Treatment | Rate | Time of application | Green Foxtail: Control Ratings[a] July 11 | Green Foxtail: Control Ratings[a] Aug. 11 | Green Foxtail: Density[b] | Rapeseed: Tolerance Ratings[a] July 11 | Rapeseed: Tolerance Ratings[a] Aug. 11 | Rapeseed: Density[b] | Rapeseed: Seed yield[b] |
|---|---|---|---|---|---|---|---|---|---|
| | (kg/ha) | | | | (plants/$m^2$) | | | (plants/$m^2$) | (g/$m^2$) |
| Untreated | | | 0 | 0 | 178 a | 9 | 9 | 93 a | 46 g |
| Handweeded | | | 9 | 9 | 0 e | 9 | 9 | 95 a | 99 a |
| Dinitramine | 0.74 | spring | 5 | 6 | 76 bcd | 7 | 8 | 74 b | 69 def |
| Dinitramine | 0.84 | fall | 4 | 6 | 112 bc | 8 | 8 | 92 a | 68 def |
| Dinitramine | 1.68 | fall | 4 | 7 | 128 ab | 8 | 8 | 88 ab | 74 cde |
| Trifluralin | 0.84 | spring | 6 | 7 | 112 bc | 7 | 9 | 82 ab | 94 ab |
| Trifluralin | 1.12 | fall | 7 | 8 | 80 bcd | 8 | 9 | 98 a | 91 abc |
| Trifluralin | 2.24 | fall | 8 | 8 | 58 cde | 8 | 9 | 82 ab | 91 abc |
| Pendimethalin | 2.2 | spring | 7 | 8 | 74 bcd | 8 | 8 | 86 ab | 74 cde |
| Pendimethalin | 3.0 | fall | 8 | 8 | 42 de | 8 | 8 | 92 a | 77 bcd |
| Pendimethalin | 4.5 | fall | 8 | 9 | 0 e | 7 | 8 | 74 b | 69 def |
| Triallate | 1.68 | spring | 2 | 0 | 128 ab | 9 | 8 | 97 a | 64 def |
| Triallate | 1.68 | fall | 2 | 0 | 120 abc | 8 | 8 | 91 a | 53 fg |
| Triallate | 3.36 | fall | 3 | 1 | 46 de | 8 | 8 | 93 a | 59 efg |

[a]Weed control and crop tolerance were assessed on a 0-9 scale where 0 = complete kill of the crop and no effect on the weed and 9 = complete tolerance of the crop and complete control of the weed.

[b]Crop and weed densities and seed yield followed by the same letter within a column are not significantly different at the 5% level according to Duncan's Multiple Range Test.

a.i. in 1979 was not as effective as it had been the year before. Fall-applied pendimethalin at 3.0 kg/ha a.i. was equal to or better than the spring treatment in controlling green foxtail. Wild oat control in 1978 with all pendimethalin treatments was very good.

As expected, commercially recommended rates of fall- or spring-applied triallate had little or no effect on green foxtail populations (Tables 6 and 8). Wild oat control was excellent in 1978 with the spring application of triallate resulting in slightly better control than the fall treatment.

Rapeseed tolerance ratings, stand densities, and seed yields are presented in Tables 7 and 8. In 1978, all treatments of dinitramine and pendimethalin significantly reduced stand densities but the level of weed control more than compensated for the stand reduction. Only the spring application and the high rate of fall-applied pendimethalin significantly reduced rapeseed seed yields. Spring-applied dinitramine and fall-applied pendimethalin at 4.5 kg/ha a.i. significantly reduced the rapeseed stand in 1979. Rapeseed was more susceptible to injury from dinitramine and pendimethalin in 1978 than in 1979, and there was little difference in tolerance between a spring or fall application of either herbicide during 1978.

In both years, trifluralin showed the least effect on rapeseed stand densities and resulted in the best yields of the herbicide treatments. Fall application of trifluralin showed slightly higher rapeseed densities than the equivalent spring treatment although this was not reflected in higher yields.

As expected, triallate treatments had little, if any, effect on rapeseed densities in both years of the study (Tables 7 and 8). However, in 1979 seed yields from all triallate-treated plots were significantly lower than from the hand-weeded control. High infestations of broadleaf weeds including wild buckwheat, redroot pigweed, and lambsquarters early in the growing season may have severely affected yield potential in the triallate plots prior to the overall application of benazolin in 1979. The dinitroaniline herbicides controlled most of the broadleaf weeds which eliminated this source of competition with the crop and resulted in higher seed yields than in the triallate-treated plots.

## Discussion

### Flax Experiments

EPTC applied in the spring resulted in better control of green foxtail than when it was applied in the fall, although the spring application showed less crop tolerance (Tables 3, 4, and 5). Plots treated with EPTC in the fall at 3.3 kg/ha showed significant flax seed yield reductions compared to the hand-weeded plots, whereas the spring treatments of EPTC did not significantly depress yields (Tables 4 and 5). The superior control of green foxtail with the spring application compared to the fall application of EPTC resulted in less weed competition with the flax and allowed these plots to overcome the effects of stand reduction.

Gray and Weierich (1965) reported increased losses of EPTC as soil moisture and soil temperature increased. In the study reported here, fall application of EPTC resulted in less green foxtail control than a spring application. High levels of soil moisture early in the spring may result in significant losses of EPTC from fall-treated plots well before the crop is even seeded and thus may account for this difference in weed control even though the fall treatment was applied at a higher rate than the spring treatment. Further losses through volatilization could occur with either a spring or fall application of EPTC prior to incorporation of the herbicide which could lead to variable levels of weed control. Current provincial recommendations are to incorporate EPTC immediately after application to minimize losses from the soil surface.

In both years of the study, all triallate treatments resulted in lower flax seed yields than the hand-weeded control, although this reduction was significant only for the spring application of either granular or EC formulations in the 1978 trial (Tables 4 and 5). Green foxtail infestations were equivalent to that in the weedy control for these two treatments which is probably the reason for the significant yield reduction. Although some of the triallate treatments resulted in significantly reduced levels of green foxtail populations, it seems unlikely that this was due to herbicide toxicity since this chemical is very specific for control of wild oats. Generally, the poor control of green foxtail by triallate is likely the reason for the reduction seen in flax seed yields.

Fall and spring applications of granular or EC formulations of triallate resulted in excellent control of wild oats in the one year that there was a sufficient infestation to allow data to be collected (Table 3). The spring application of granular triallate was somewhat less satisfactory in controlling wild oats; however, this was not shown to be significantly different from other triallate treatments. These results are similar to those reported by Miller and Nalewaja (1980) who found that control of wild oats was greater with fall applications of granular triallate than with liquid triallate. Spring-applied granular triallate was the least effective in controlling wild oats in their study. They speculated this was a result of better herbicide distribution in the soil with fall-applied granules or spring-applied liquid triallate.

The effect of the triallate treatments on flax stand density is uncertain since considerable variation occurred from one year to the next. Since this herbicide is very specific for wild oat control, it seems unlikely that an effect on flax would occur. The significant reductions in flax densities shown in Tables 4 and 5 with some of the triallate treatments are probably due to some factor other than herbicide injury, such as variation in depths of seeding or unevenness of seedbed preparation.

In both years of the study, fall-applied trifluralin at 1.12 kg/ha a.i. resulted in higher flax seed yields than a spring application at 0.84 kg/ha, although the differences were not significant (Tables 4 and 5). While the fall application had less effect on the flax stand than the spring treatment, it provided control of green foxtail and wild oats that was at least equivalent to the spring application of trifluralin. Thus, the improved flax tolerance following a fall application of trifluralin combined with excellent weed control may partially explain the higher seed yields obtained with fall-applied trifluralin compared to the spring application. Flax showed better tolerance to all trifluralin treatments in 1979 than in 1978 which probably results from lower concentrations of the herbicide in the top 5 cm of soil as shown in the data presented in Chapter III.

Rapeseed Experiments

Control of green foxtail with dinitramine, trifluralin, and pendimethalin was variable in the 2 years of the study (Tables 6 and 8). The variation in the results may be related to differences in weather conditions during the spring of 1978 and 1979. Mean monthly temperatures from March through May, 1979 were 2 to 7$^{\circ}$ C cooler than the same period during 1978 (Appendix Figure 1). Furthermore, during March, April, and May of 1979 precipitation was about 100 mm above the long term average, while during the same period in 1978 the area received about 50 mm above the long term average precipitation level (Appendix Table 2). Thus, the cool, wet spring of 1979 probably retarded weed seed germination that year. Combined with this, herbicide levels in the top 5 cm of soil for dinitramine and trifluralin treatments were less at the time of seeding in 1979 than in 1978, as reported in Chapter III. Thus, lower herbicide levels in the soil and delayed germination may have allowed more green foxtail plants to escape injury from the dinitroaniline herbicides in 1979.

Control of green foxtail by the trifluralin treatments in the rapeseed experiment during 1979 was less effective than the same treatments in the flax experiment in the same season (Tables 5 and 8). However, green foxtail infestations were much higher in the untreated plots in the rapeseed experiment with 178 plants per $m^2$ compared to 76 plants per $m^2$ in the flax experiment. Consequently, the number of green foxtail plants escaping injury in the rapeseed experiment was larger than the number escaping injury in the flax experiment. Differences in trifluralin concentrations in the soil between the two experiments may also affect the amount of phytotoxicity but this difference was not determined.

In both years of the study, rapeseed appeared to be more tolerant to fall applications of the herbicides than to spring treatments. In the case of dinitramine and pendimethalin applications, less injury was noted with all treatments in 1979 than in 1978 (Tables 7 and 8). As mentioned earlier, soil concentrations of dinitramine at time of seeding were lower in 1979 than in 1978 which may account for less crop injury in 1979. If pendimethalin also had lower soil concentrations in 1979, then the possibility of less crop injury due to this factor exists.

Chow (1976) reported that dinitramine at 0.84 kg/ha a.i. caused slight injury to rapeseed seedlings during emergence, whereas trifluralin and triallate did not. However, because green foxtail and wild oat control was good, the dinitramine treatment did not affect final seed yield. In the present study, in 1978 when the dinitramine treatments resulted in excellent weed control, rapeseed yields were not reduced significantly even though there were significant stand reductions. However, in 1979 the dinitramine treatments had little effect on the crop, but due to poor control of green foxtail, yields were significantly reduced compared to the untreated control.

Fall applications of dinitramine, pendimethalin, or trifluralin resulted in control of green foxtail that was equivalent to a spring application of the same chemical (Tables 6 and 8). When this is combined with improved tolerance of rapeseed following a fall herbicide application, then the fall treatment is more desirable in terms of both crop tolerance and weed control, especially with dinitramine and pendimethalin. Betts and Morrison (1979) reported that either fall or spring applications of trifluralin resulted in acceptable control of green foxtail and wild oats which is similar to the results found in the flax and rapeseed experiments in this study. They also found improved fababean tolerance to fall applications of metribuzin, especially when tank-mixed with trifluralin, compared to similar spring treatments.

As expected, triallate applications had little effect on rapeseed although seed yields were significantly reduced in the second year of the study. In that year, there was a heavy infestation of broadleaf weeds including wild buckwheat, redroot pigweed, and common lambsquarters which strongly competed with the rapeseed in the triallate-treated plots. This competition during early seedling development is the probable reason for the yield reductions associated with the triallate treatments.

In summary, the field studies with fall and spring applications of soil-applied herbicides in flax and rapeseed have shown the following:

1) Fall applications of trifluralin, dinitramine, and pendimethalin are generally less injurious to rapeseed than spring applications.
2) Fall applications of trifluralin, dinitramine, pendimethalin, and triallate provide levels of weed control that are comparable to spring applications.
3) In flax, fall applications of trifluralin are better than spring treatments, as fall applications resulted in better crop tolerance, equivalent weed control, and higher seed yields.

4) Fall applications of EPTC in flax can result in poor weed control and concomitant reductions in seed yield.

5) Triallate by itself is unsuitable for use in flax and rapeseed if other weeds besides wild oats are a problem.

# CHAPTER III

# SOIL PERSISTENCE AND PHYTOTOXICITY

## Introduction

Recent weed surveys in Manitoba have indicated that triallate and trifluralin are widely used by farmers in the province (Thomas, 1979, 1980). In 1978 and 1979, about 15% of the surveyed cropland was treated with triallate for wild oat control. In addition to this, about 18% of the fields in the province received trifluralin applications in 1979. About 40% of the triallate and about 30% of the trifluralin was fall-applied. Obviously, these two herbicides have become widely accepted by farmers for use in their weed control programs.

Considering that a large portion of the triallate- and trifluralin-treated acreage is treated in the fall, these herbicides must persist at sufficient levels to achieve satisfactory weed control the following spring. Current provincial recommendations suggest the use of higher rates of trifluralin when it is applied in the fall than when it is applied in the spring, whereas, with triallate fall and spring application rates are the same[1]. However, research in Saskatchewan shows that between 45% and 60% of the applied triallate dissipated during the winter months following a fall application (Smith, 1975). Considerable losses of trifluralin over the winter months have also been reported (Smith, 1979). If such losses are occurring under field conditions, then the level of weed control would likely be impaired

[1] 1982 Guide to Chemical Weed Control, Manitoba Agriculture.

unless fall application rates were substantially higher than spring rates.

Persistence studies under prairie conditions have shown considerable variation in the amount of triallate and trifluralin that remains in the soil at the end of the growing season (Pritchard and Stobbe, 1979; Smith, 1972, 1975, 1979; Smith and Hayden, 1976). Webster et al. (1978) determined that extractable trifluralin residues were quite similar in four Manitoba soils 16 weeks after application, ranging from 40% to 47%. Interestingly, the Almasippi loamy sand soil (organic matter 2.9%, clay 8%) which showed the least persistence of trifluralin, displayed the most phytotoxicity to wild oats. These researchers suggested that the availability of phytotoxic residues was related to clay content of the soil. This suggests that available phytotoxic residues are more important than extractable soil residues in assessing whether carryover of soil-applied herbicides to the next cropping season will be a problem.

The current study was initiated to assess the persistence of several soil-applied herbicides applied to an Almasippi very fine sandy loam soil under normal field cropping practice. Further studies were conducted to assess the duration of weed control and the potential for carryover problems occurring.

## Materials and Methods

### Sampling

Soil samples from the field trials outlined in Chapter II were collected at the time of seeding, 6 weeks after seeding, and after the plots were harvested (15 weeks in 1978 or 18 weeks in 1979, after seeding). Composite samples were collected from the top 5 cm of soil from four sites selected randomly in each field plot. Sampling was done by pressing a metal can, 6 cm in diameter, into the soil to the desired depth. All four replicates of each treatment were sampled and stored separately for each sampling date. All samples were air-dried at room temperature and stored at -30° C prior to residue analysis and phytotoxicity studies.

Determination of Soil Residues

Analytical determinations of soil residues of trifluralin, emulsifiable and granular formulations of triallate, and dinitramine were conducted using an extraction procedure described by Smith (1974) with some modifications. Twenty grams of the air-dry soil sample were placed into a 100 mL beaker with 50 mL of acetonitrile-water (9:1) and extracted for 2 minutes using an Artek Sonic Dismembrator at maximum power. For each sampling date of each plot, two sub-samples were extracted in this manner. The supernatant was transferred to a centrifuge tube and centrifuged for 5 minutes. A 25 mL portion of the acetonitrile solution was pipetted into a 250 mL separatory funnel containing 150 mL of distilled water and 20 mL of saturated aqueous sodium sulfate solution. The mixture was shaken twice with 25 mL portions of n-hexane and the aqueous layer was discarded. The hexane phase was dried over anhydrous sodium sulfate in a screw-capped glass bottle and stored in darkness until analyzed by gas chromatography.

Extraction efficiency for each herbicide in the Almasippi very fine sandy loam soil was determined according to a method described by Pritchard (1976), with modifications. Five milliliters of herbicide stock solution in hexane was added to 100 g samples of air-dry, untreated soil in 570 mL plastic bags to give soil concentrations of 0.25, 0.50, and 1.00 ppmw. The bags were sealed and shaken vigorously to ensure even herbicide distribution. The bags were then opened and exposed to the air for several hours to allow the hexane to evaporate from the soil. After resealing, the bags were stored at -30° C for 7 days before the herbicide was extracted. Two samples from each herbicide concentration were extracted as described previously. The extraction efficiencies for trifluralin, triallate, and dinitramine were 88, 94, and 97%, respectively.

Concentrations of extracted samples and standards of trifluralin, triallate, and dinitramine were determined by analyzing 1 to 5 $\mu$L aliquots of each sample on a gas chromatograph. Standard curves for each herbicide were obtained by preparing stock solutions of each compound in n-hexane. Concentrations of the standard solutions were 0.003 to 0.3 ng/$\mu$L for trifluralin and triallate, and 0.024 to 0.24 ng/$\mu$L for dinitramine. Standard curves were determined by plotting the log of the peak height (mm) versus the log of the herbicide quantity (pg) and used to calculate herbicide concentration in the extracted samples. The calculated concentration in the hexane extraction was used to determine soil concentration.

Aliquot injections of each sample were analyzed on a Varian Aerograph Series 1800 gas chromatograph fitted with a tritium foil, electron capture detector, and a 1.1 m glass column with an inside diameter of 4 mm and packed with 5% OV on 80-100 mesh chromasorb W, AW, DMCS. Prepurified nitrogen was used as the carrier gas at a flow rate of 50 mL/min. Temperatures of the injection port, column oven, and detector were 220, 165, and 225° C, respectively. Retention times for trifluralin, triallate, and dinitramine were 1.07, 1.31, and 1.23 minutes, respectively.

Phytotoxicity Studies

To determine the effect of time on the phytotoxicity of soil-applied herbicides to weeds, yellow foxtail or wild oats were grown under growth room conditions in soil samples taken at three dates from the top 5 cm from the field plots reported in Chapter II. The initial dosages of each herbicide are shown in Tables 1 and 2, and the dates and methods of soil sampling are the same as reported for the soil residue determination. Yellow foxtail was used as the susceptible weed species for trifluralin, dinitramine, pendimethalin, and EPTC treatments, while for the two formulations of triallate, wild oats was the test species.

Each herbicide was examined separately using a split-split plot experimental design with four replicates, with each replicate in the growth room corresponding to a similar replicate from the field trials. With the exception of the triallate experiment, the main plots were the year in which the soil was sampled with sub-plots being the dosage of the chemical and sub-subplots being the time of soil sampling. For triallate, the 2 years of soil sampling were conducted as separate experiments with main plots being rates of application. Sub-plots were dates of soil sampling and sub-subplots were herbicide formulation.

For each sub-subplot, about 350 g of air-dry, sampled soil was placed into a 10 cm diameter pot. Twenty seeds of yellow foxtail or wild oats were placed on the soil surface and then covered with 1.5 to 2.0 cm of the soil (about 150 g) and then watered. The pots were placed in a growth room under a 16 h photoperiod with a $22^{o}$ C/$16^{o}$ C day/night temperature regime, 50 to 60% R.H., and light intensity of 225 $Em^{-2}s^{-1}$. The pots were watered every 1 or 2 days to maintain soil moisture between 50 and 100% field capacity.

Shortly after emergence of the seedlings, the plants were thinned to 10 plants per pot in those cases where more than 10 plants had emerged. The number of plants in each pot (sub-subplot) was recorded. Three weeks after emergence of the plants in the untreated pots, the shoots were harvested at ground level and were dried in an oven at $80^{o}$ C for 48 h. Once dried, the plants were weighed and the results recorded on a dry weight per plant basis.

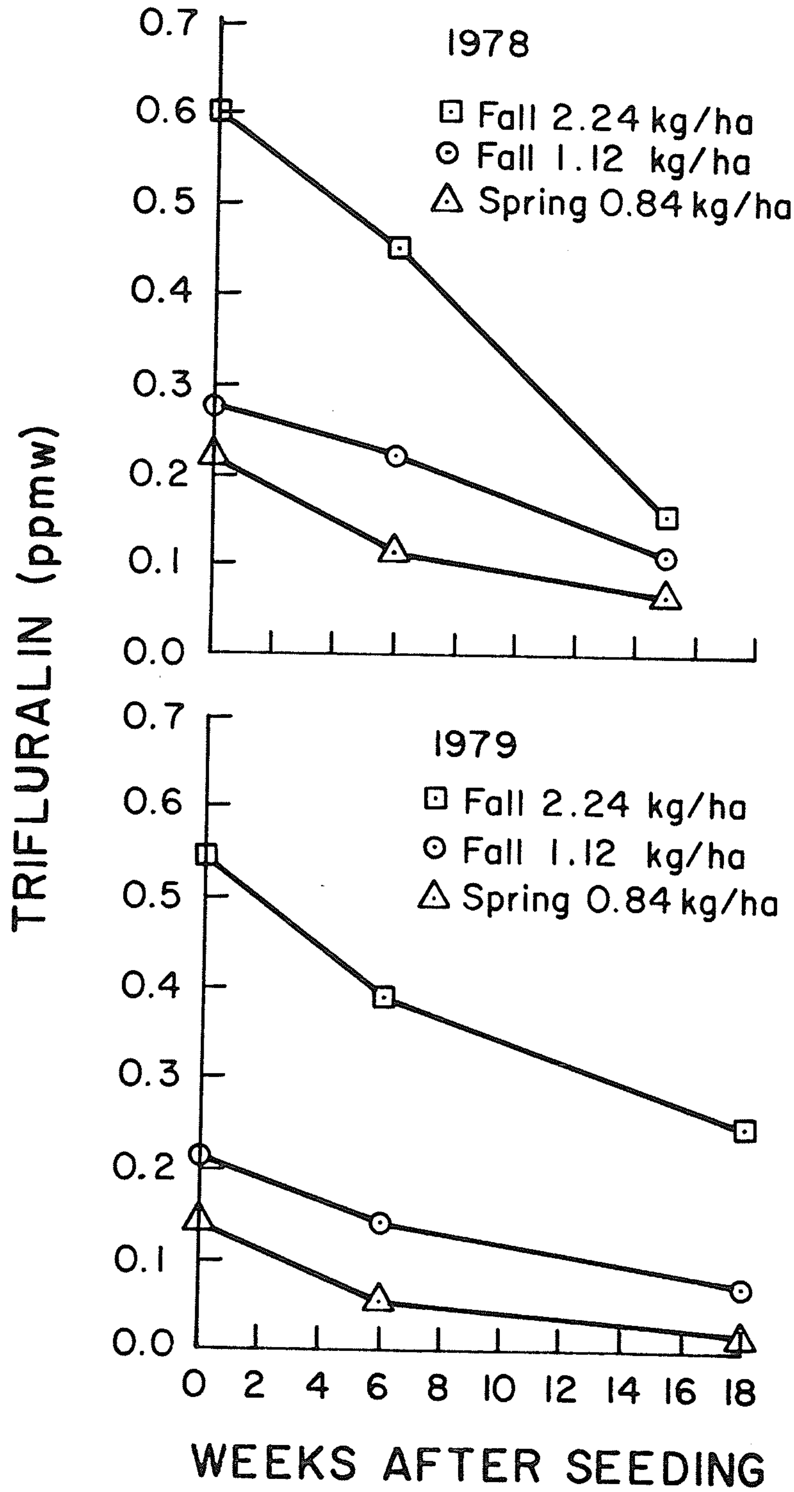
## Results

### Soil Persistence of Trifluralin, Dinitramine, and Triallate

Actual soil concentration for each of the four replicates of trifluralin-, dinitramine-, and triallate-treated plots, expressed as ppmw at the selected sampling intervals, are reported in Appendix Tables 3 to 10. Because there was considerable variation in soil concentrations between the replicates for each herbicide application rate, the values of the four replicates at each sampling date were averaged. These mean soil concentrations were plotted for the different sampling dates in Figures 1, 2, 3, and 4.

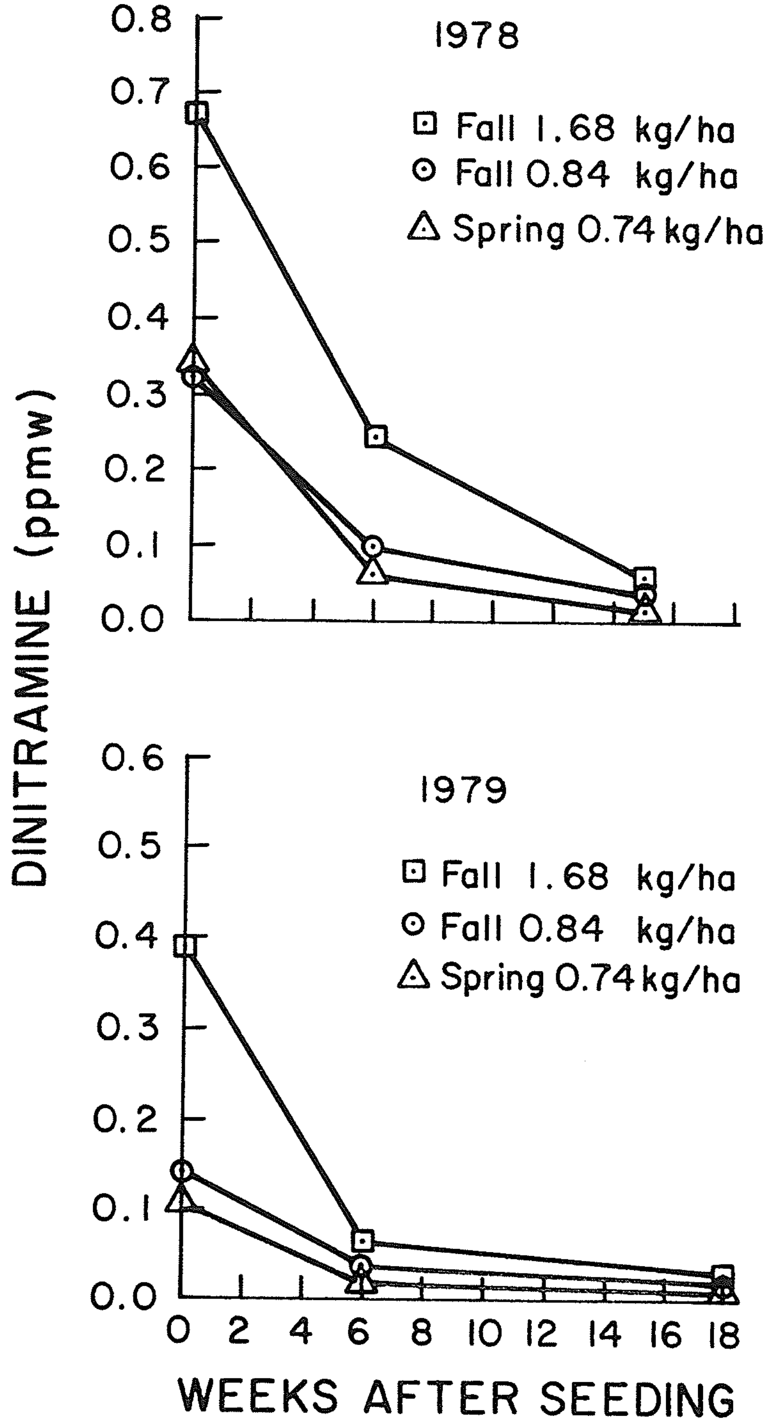
The average soil concentrations of trifluralin in the top 5 cm of soil at 0, 6, and 15 or 18 weeks after seeding is shown in Figure 1. When trifluralin was applied in the fall at 2.24 kg/ha, 25 and 45% of the amount present at the time of seeding remained after the plots were harvested in 1978 and 1979, respectively. During both years, soil concentrations of trifluralin were higher in plots treated in the fall at 1.12 kg/ha than in plots treated in the spring at 0.84 kg/ha. For all three application rates of trifluralin, soil concentrations were

Figure 1. Persistence of fall and spring applications of trifluralin in 1978 and 1979.



1978
Fall 2.24 kg/ha
Fall 1.12 kg/ha
Spring 0.84 kg/ha
1979
Fall 2.24 kg/ha
Fall 1.12 kg/ha
Spring 0.84 kg/ha
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
TRIFLURALIN (ppmw)
0 2 4 6 8 10 12 14 16 18
WEEKS AFTER SEEDING

Figure 2. Persistence of fall and spring applications of dinitramine in 1978 and 1979.


1978
Fall 1.68 kg/ha
Fall 0.84 kg/ha
Spring 0.74 kg/ha
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
DINITRAMINE (ppmw)
1979
Fall 1.68 kg/ha
Fall 0.84 kg/ha
Spring 0.74 kg/ha
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 2 4 6 8 10 12 14 16 18
WEEKS AFTER SEEDING

higher at the time of seeding in 1978 than in 1979.

Soil concentrations of dinitramine in the top 5 cm of soil at the selected sampling dates are shown in Figure 2. During both years, there was little difference in soil concentrations of dinitramine at any of the sampling dates when it was applied either in the fall at 0.84 kg/ha or in the spring at 0.74 kg/ha. When dinitramine was applied in the fall at 1.68 kg/ha, soil concentrations at time of seeding were much higher than in the other two treatments. However, the post-harvest samples showed that by the end of the growing season this difference was greatly diminished. In no instance was there more than 13% of the dinitramine present at the time of seeding remaining in the post-harvest soil samples. The actual values ranged from a low of just under 2% for the 1978 spring treatment to a high of just over 12% for the fall application at 0.84 kg/ha in 1978. For the spring treatment and the lower fall treatment, between 20 and 30% of the dinitramine found at time of seeding was present in the samples taken 6 weeks after seeding. As with trifluralin, soil concentrations of all dinitramine treatments were initially higher at the time of seeding in 1978 than in 1979.

Average soil concentrations of the granular (G) and emulsifiable concentrate (EC) formulations of triallate in the top 5 cm of soil during the growing season are shown in Figure 3 (1978) and Figure 4 (1979). During 1978, soil concentrations were higher with G triallate than with the EC formulation at every sampling date when similar treatments are compared. When either formulation of triallate was applied at 1.68 kg/ha, the fall treatment resulted in higher soil levels than the spring treatment at the time of seeding. This difference was not

Figure 3. Persistence of fall and spring applications of EC and G formulations of triallate in 1978.

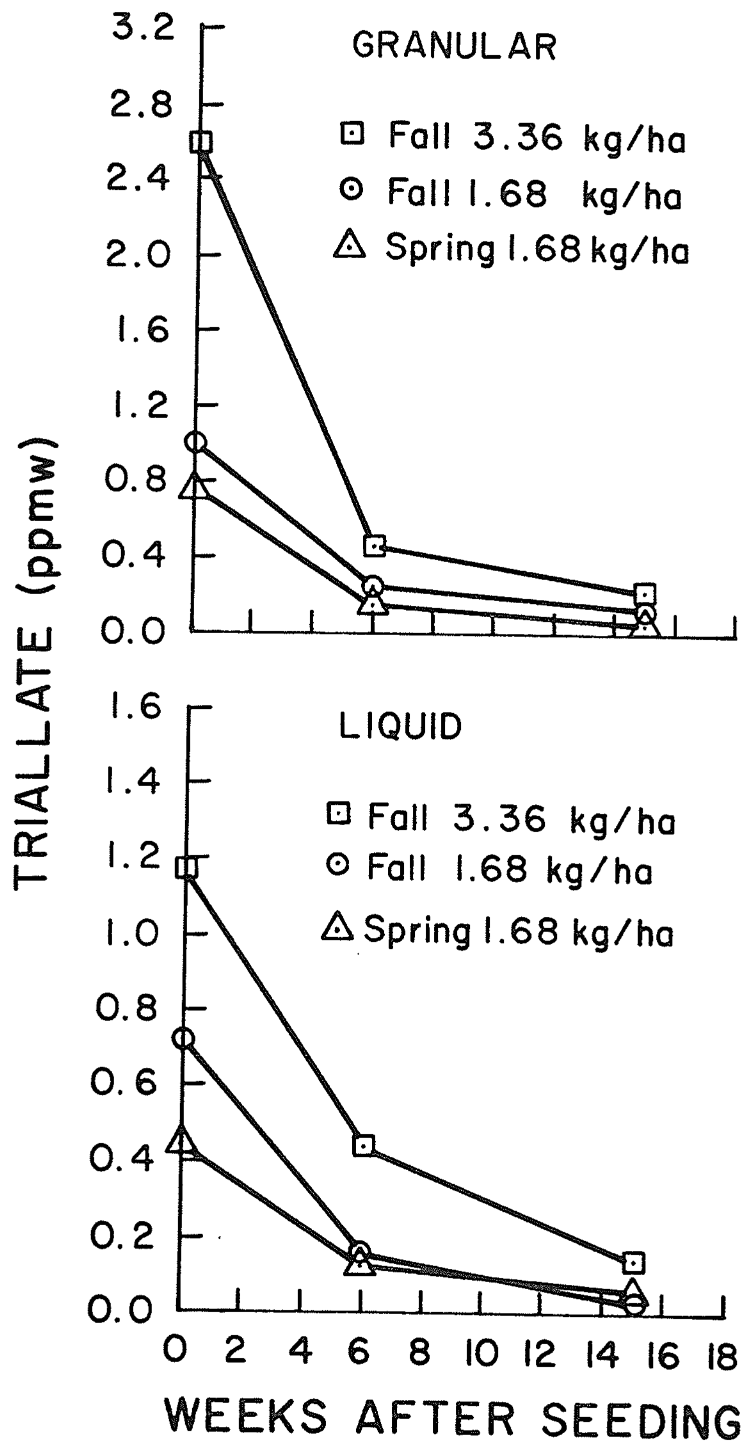
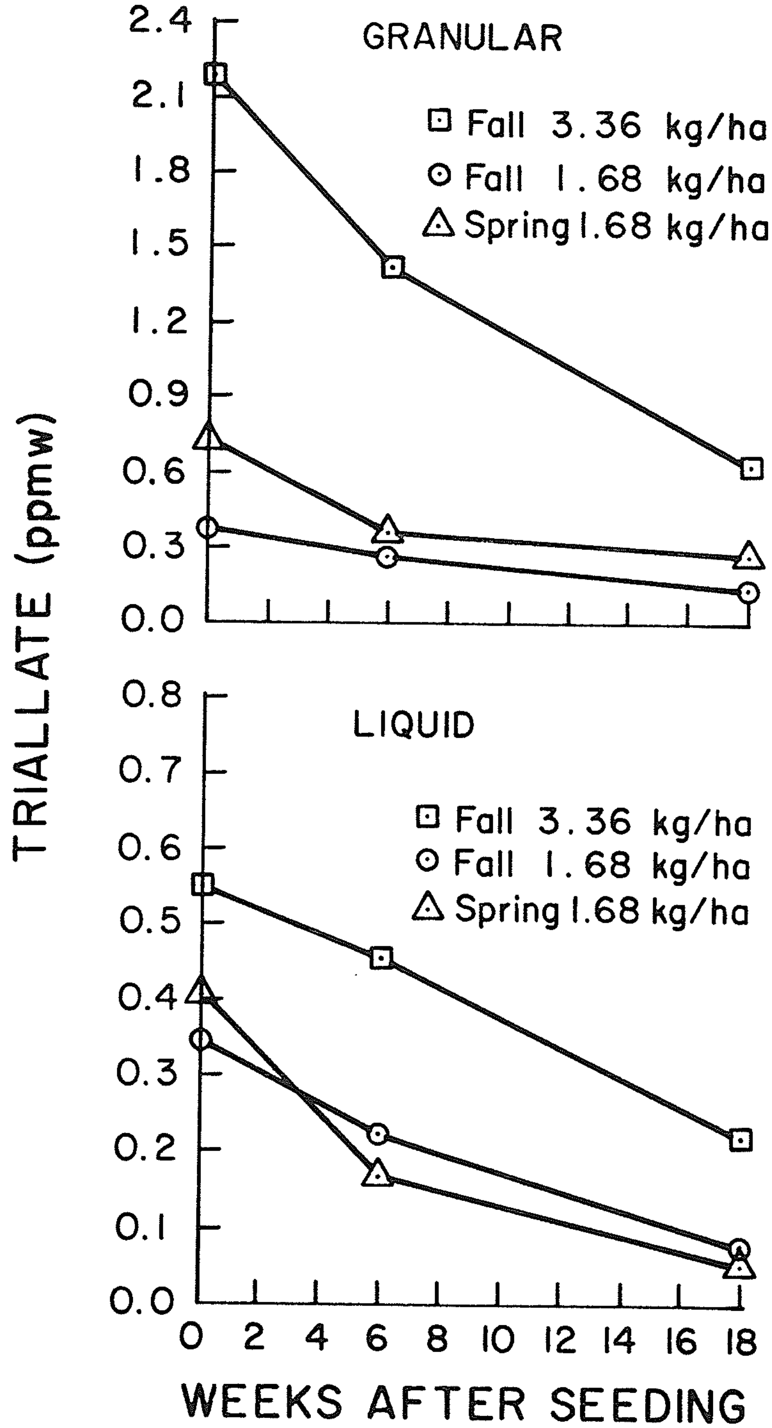

GRANULAR
Fall 3.36 kg/ha
Fall 1.68 kg/ha
Spring 1.68 kg/ha
LIQUID
Fall 3.36 kg/ha
Fall 1.68 kg/ha
Spring 1.68 kg/ha
TRIALLATE (ppmw)
WEEKS AFTER SEEDING
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
1.4
1.0
0.6
0.2
0 2 4 6 8 10 12 14 16 18

Figure 4. Persistence of fall and spring applications of EC and G formulations of triallate in 1979.


GRANULAR
Fall 3.36 kg/ha
Fall 1.68 kg/ha
Spring 1.68 kg/ha
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0
TRIALLATE (ppmw)
LIQUID
Fall 3.36 kg/ha
Fall 1.68 kg/ha
Spring 1.68 kg/ha
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 2 4 6 8 10 12 14 16 18
WEEKS AFTER SEEDING

apparent at the final sampling date. In considering all of the triallate treatments in 1978, between 7 and 14% of the triallate found at time of seeding was present in the post-harvest soil samples.

In 1979, initial soil samples showed higher levels of triallate from the granular formulation than from the EC formulation (Figure 4 and Appendix Tables 9 and 10). When compared to the results of 1978, the spring application of triallate at 1.68 kg/ha resulted in higher initial soil concentrations than the equivalent fall treatment. As was found with trifluralin and dinitramine, the initial levels of triallate in 1979 were lower than those found in 1978. The persistence of triallate, as a percentage of that present at time of seeding, was greater in 1979 than in 1978, especially with the granular formulation.

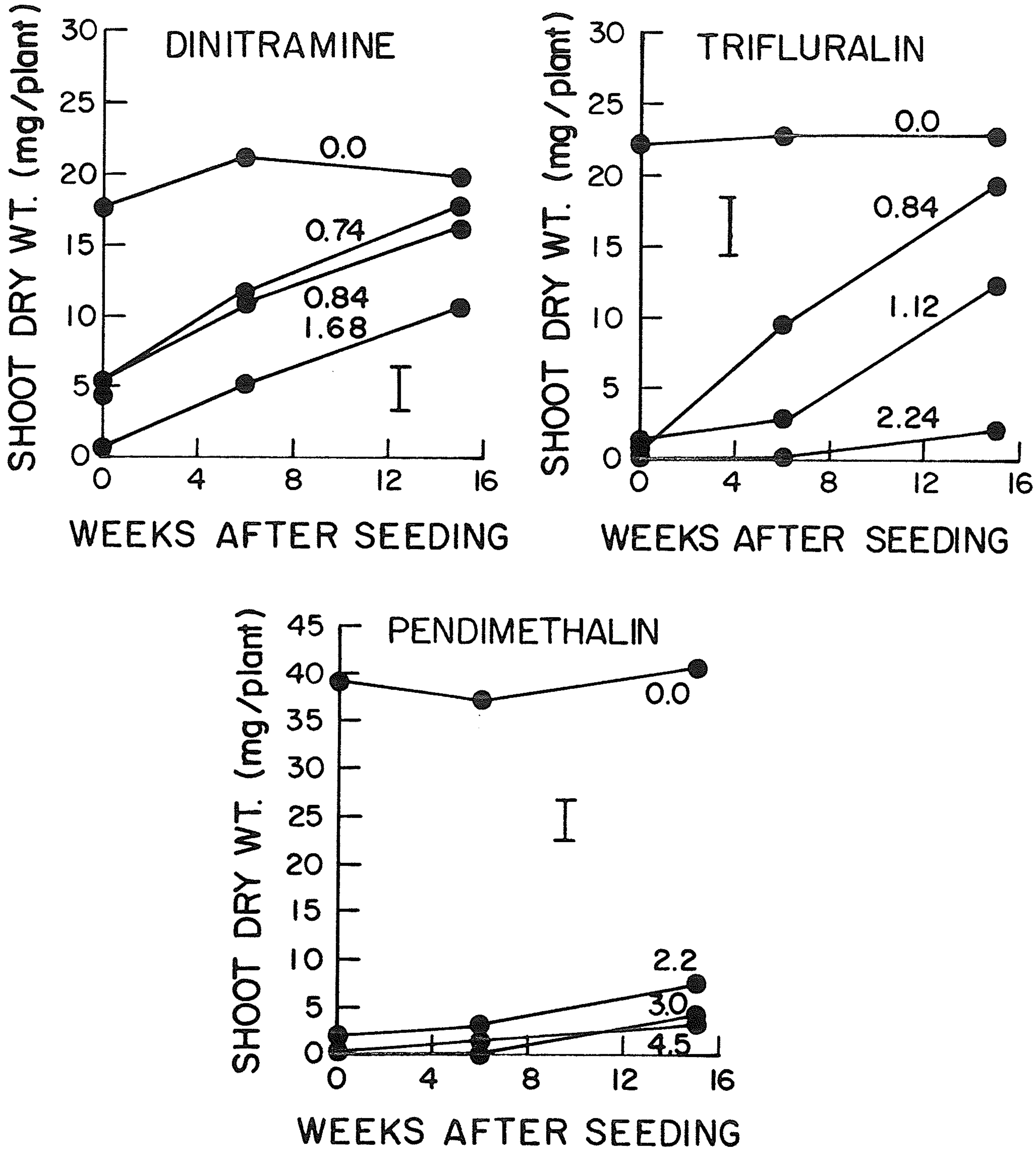
Phytotoxicity of Soil Residues

The effects of date of sampling on shoot growth of yellow foxtail following soil applications of dinitramine (Figure 5a and Plate 1), trifluralin (Figure 5b and Plate 2), and pendimethalin (Figure 5c and Plate 3) are shown 21 days after plants in the untreated plots had emerged. Shoot dry weights shown in Figure 5 are the average of the two years of soil sampling reported in the Materials and Methods of this chaper.

With dinitramine, the 1.68 kg/ha fall application showed the most effect on yellow foxtail shoot growth. Shoot dry weights (with the high fall treatment) were significantly lower than for the other treatments for all sampling dates (Figure 5a). As seen in Plates 1b and c, fall-applied dinitramine at 1.68 kg/ha resulted in a considerable growth reduction of yellow foxtail even in the soil samples taken after the field plots were harvested. Characteristically, there was a reduction

Figure 5. Phytotoxicity of soil residues of trifluralin, dinitramine, and pendimethalin to yellow foxtail.

Vertical bars represent Tukey's h.s.d. values at 5%.


DINITRAMINE
SHOOT DRY WT. (mg/plant)
30
25
20
15
10
5
0
0.0
0.74
0.84
1.68
0
4
8
12
16
WEEKS AFTER SEEDING
TRIFLURALIN
SHOOT DRY WT. (mg/plant)
30
25
20
15
10
5
0
0.0
0.84
1.12
2.24
0
4
8
12
16
WEEKS AFTER SEEDING
PENDIMETHALIN
SHOOT DRY WT. (mg/plant)
45
40
35
30
25
20
15
10
5
0
0.0
2.2
3.0
4.5
0
4
8
12
16
WEEKS AFTER SEEDING

in the number and size of the leaves produced by the yellow foxtail seedlings grown in the soil taken from plots treated in the fall with dinitramine at 1.68 kg/ha.

With the commercially recommended rates of dinitramine, there was little difference in control of yellow foxtail with the spring treatment of 0.74 kg/ha and the fall treatment of 0.84 kg/ha (Figure 5a). Very little growth of yellow foxtail occurred in soil samples taken at the time of seeding with either of these treatments (Plates 1d and g). Six weeks after seeding, both treatments still controlled yellow foxtail with about a 50% growth reduction compared to the untreated control (Plate 1e and h). This level of control was very similar to that seen in the post-harvest soil samples with the 1.68 kg/ha fall application. Growth of yellow foxtail in soil sampled after harvest following a spring application or the lower fall application of dinitramine was fairly similar. However, when compared to the untreated control, yellow foxtail growth was significantly reduced in the fall-treated soil, whereas in the spring-treated soil, the growth reduction was not significant.

Growth of yellow foxtail in trifluralin treated soil is shown in Plate 2 with shoot dry weights at the three soil sampling presented in Figure 5b. At all soil sampling dates, shoot dry weight of yellow foxtail in trifluralin treated soil was significantly less than in the untreated soil, except for the post-harvest samples taken from spring-treated plots (Figure 5b). As shown in Plate 2, growth of yellow foxtail in untreated soil (a) was more vigorous than in most of the treated soils (b-i). Growth in post-harvest soil samples taken from field plots treated in the spring with 0.84 kg/ha trifluralin was sig-

Plate 1. Growth of yellow foxtail in dinitramine-treated soil at different soil sampling dates.

a) untreated control; b) 1.68 kg/ha fall-applied (F) dinitramine sampled 6 weeks after seeding; c) 1.68 kg/ha F post-harvest soil sample; d) 0.74 kg/ha spring-applied (S) sampled at seeding; e) 0.74 kg/ha S sampled 6 weeks after seeding; f) 0.74 kg/ha S post-harvest soil sample; g) 0.84 kg/ha F sampled at seeding; h) 0.84 kg/ha F sampled 6 weeks after seeding; i) 0.84 kg/ha F post-harvest soil sample.

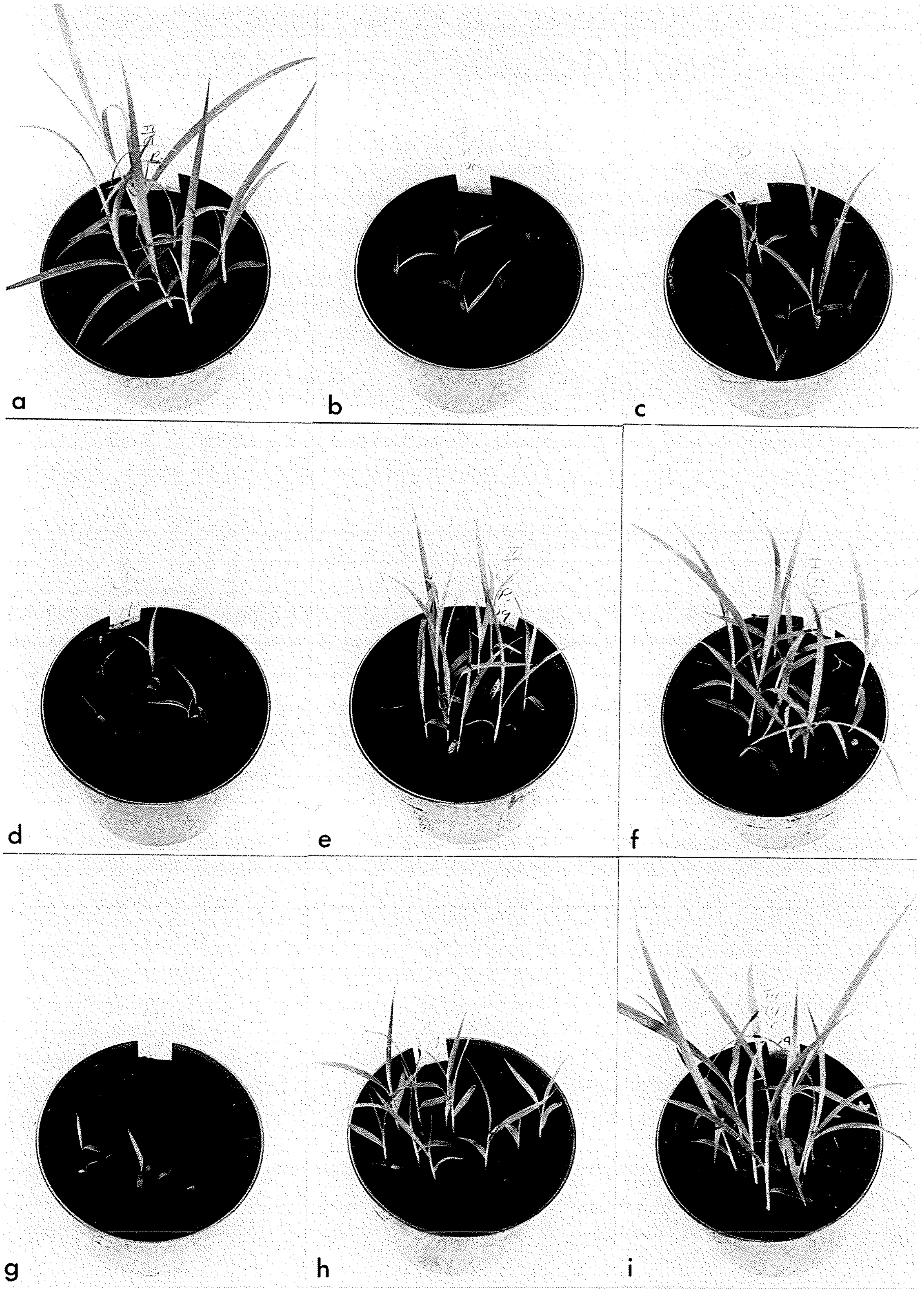

a
b
c
d
e
f
g
h
i

Plate 2. Growth of yellow foxtail in trifluralin-treated soil at different soil sampling dates.

a) untreated control; b) 1.12 kg/ha fall-applied (F) trifluralin sampled at seeding, 1979; c) 1.12 kg/ha F post-harvest soil sample, 1979; d) 0.84 kg/ha spring-applied (S) sampled at seeding, 1979; e) 0.84 kg/ha S sampled 6 weeks after seeding, 1979; f) 0.84 kg/ha S post-harvest soil sample, 1979; g) 2.24 kg/ha F post-harvest soil sample, 1979; h) 1.12 kg/ha F post-harvest soil sample, 1978; i) 0.84 kg/ha S post-harvest soil sample, 1978.

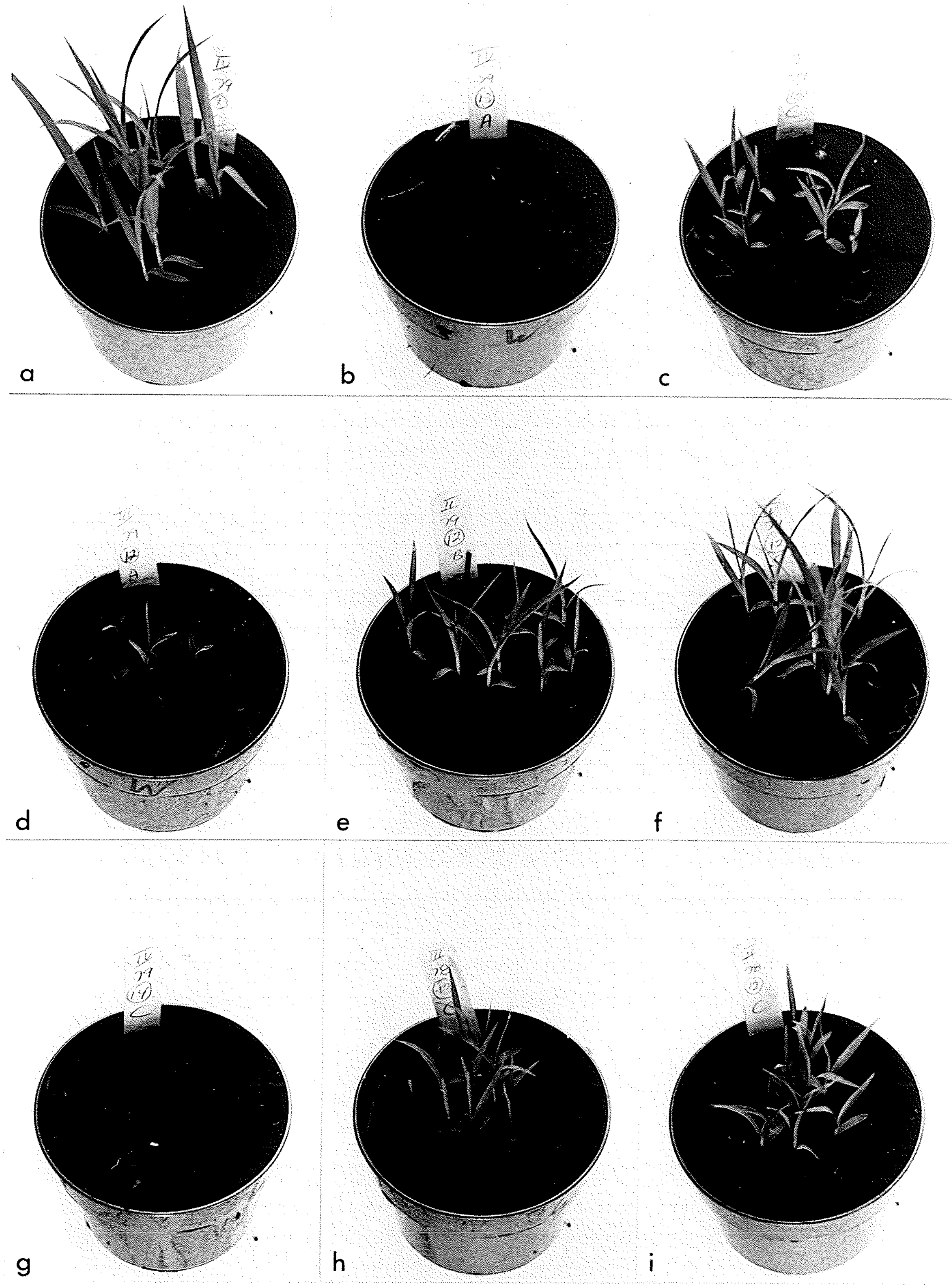
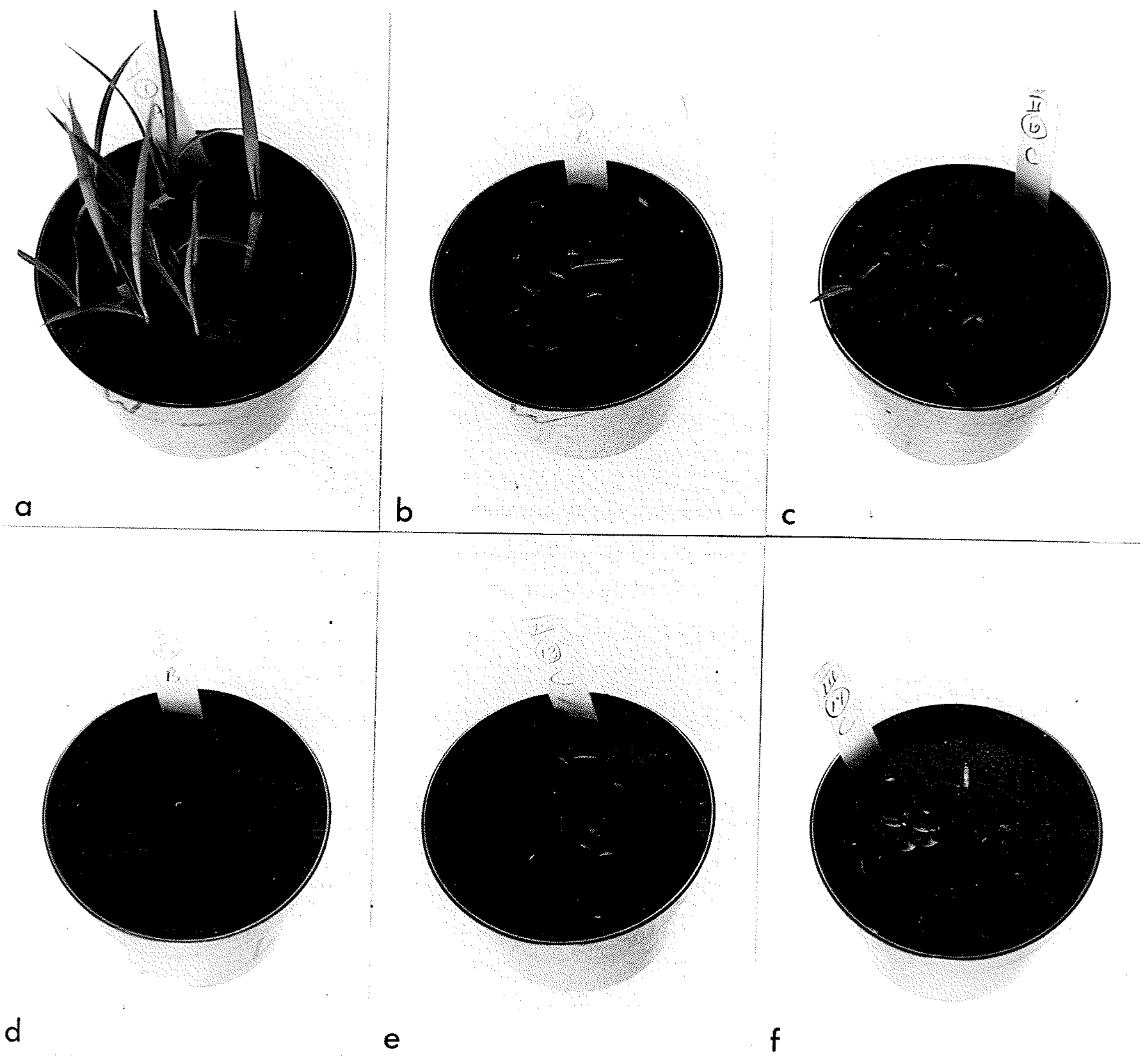

a
b
c
d
e
f
g
h
i

Plate 3. Growth of yellow foxtail in pendimethalin-treated soil at different soil sampling dates.

a) untreated control; b) 2.5 kg/ha spring-applied (S) pendimethalin sampled 6 weeks after seeding; c) 2.5 kg/ha S post-harvest soil sample; d) 3.0 kg/ha fall-applied (F) sampled 6 weeks after seeding; e) 3.0 kg/ha F post-harvest soil sample; f) 4.5 kg/ha F post-harvest soil sample.


a
b
c
d
e
f

nificantly higher than in the other trifluralin-treated soils at this sampling date (Figure 5b). This was especially evident in samples taken in 1979 where growth in the post-harvest soil sample from the spring-treated plot (Plate 2f) was nearly equal to the control. With the spring application of trifluralin, yellow foxtail growth was very similar in the 6 week soil sample in 1979 (Plate 2e) and the post-harvest sample in 1978 (Plate 2i). Mean soil concentrations of trifluralin at these two dates were very similar (Appendix Tables 5 and 6).

In soil samples taken from plots treated in the fall with 1.12 kg/ha of trifluralin, growth of yellow foxtail was significantly less than in untreated soil for all sampling dates (Figure 5b). Control of yellow foxtail was excellent in soil samples collected at the time of seeding from the fall-treated plots (Plate 2b) with little or no growth occurring while in soil samples collected after harvest (Plate 2c and h) growth was restricted to about 60% of that occurring in untreated soil. Control of yellow foxtail was significantly better with the fall application than with the spring treatment at the 6 week and post-harvest sampling dates (Figure 5b). Very little growth of yellow foxtail occurred in soil samples taken from the plots treated in the fall at 2.24 kg/ha, even in the post-harvest soil samples (Figure 5b and Plate 2g).

As seen in Plate 3 and Figure 5c, all pendimethalin treatments effectively controlled yellow foxtail at all soil sampling dates. If any growth of yellow foxtail occurred in the pendimethalin treated soil, it was restricted to a few tiny leaves (Plate 3b, c, e, and f). Often only a single leaf emerged which did not enlarge appreciably. Of the dinitroanilines tested, pendimethalin resulted in the most effective control of yellow foxtail at all soil sampling dates.

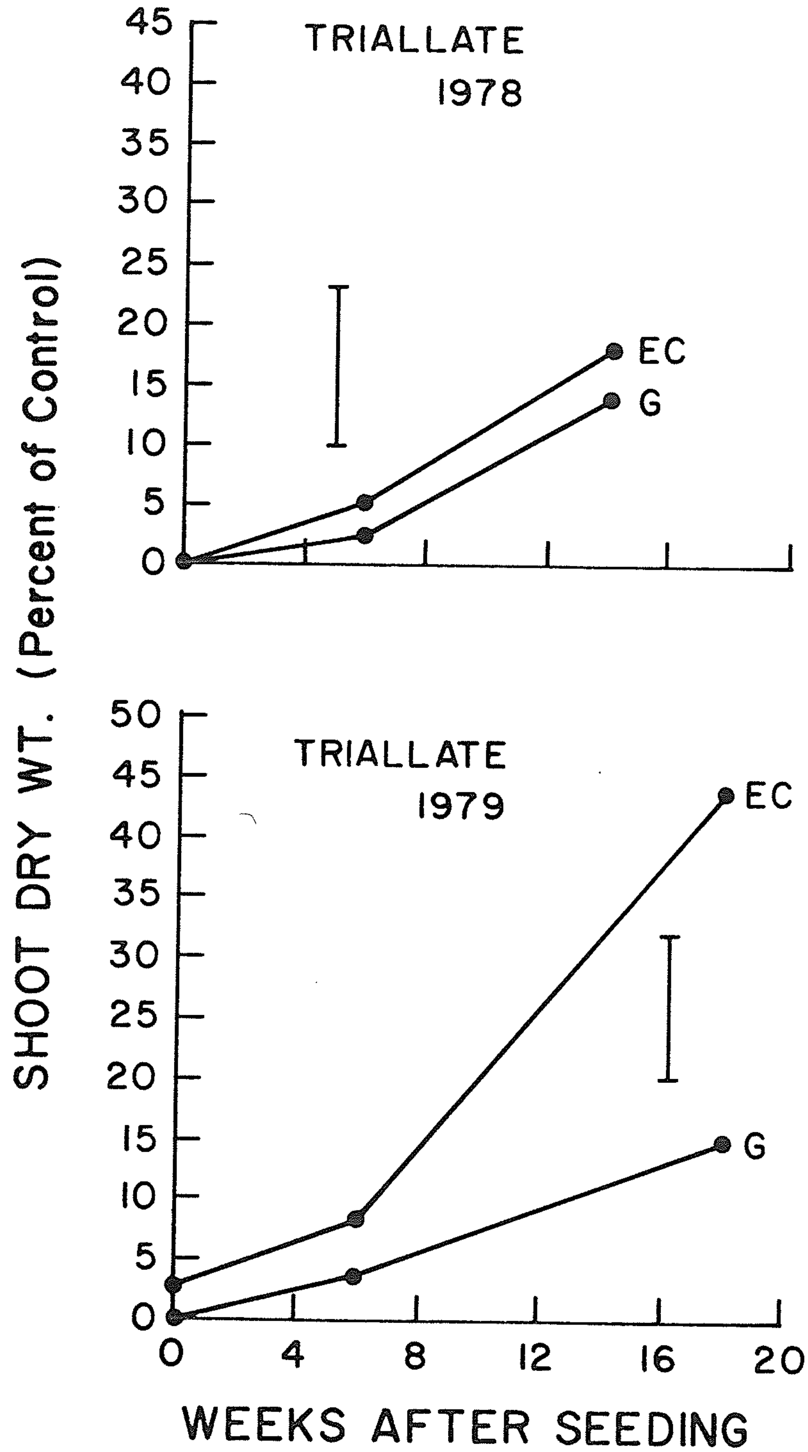
With triallate, the phytotoxicity studies were designed to compare the effectiveness of the granular (G) and emulsifiable concentrate (EC) formulations in controlling wild oats at the three sampling dates. Figure 6a shows that if all rates of triallate are considered, there was no difference between the G and EC formulations in controlling wild oats at the dates sampled in 1978. However, in the samples collected in 1979 (Figure 6b and Plate 4), the granular formulation of triallate resulted in significantly better control of wild oats than the EC formulation in the soil samples taken after harvest, as shown by the reduced shoot dry weight.

With the highly significant rate X date X formulation interaction seen in the studies with triallate, comparisons between dates of sampling, formulation, and rates of application are possible (Tables 9 and 10). From the results obtained in 1979 (Table 10), soil samples taken 18 weeks after seeding from fall applications of granular triallate showed significantly better control of wild oats than soil samples taken from plots treated with the EC formulation at 1.68 kg/ha either in the spring or fall. The spring granular treatment showed more activity on wild oats in the 18 week samples than the EC formulations but this difference was not significant. The results from soil samples taken in 1978 (Table 9) showed little difference in activity between the G and EC formulations.

Yellow foxtail shoot dry weight was significantly reduced when grown in all EPTC-treated soil that was sampled at time of seeding (Figure 7). In the samples taken 6 weeks after seeding, growth was significantly reduced compared to the control with the 2.8 kg/ha spring treatment of EPTC but not with the 3.3 kg/ha fall treatment, although

Figure 6. Phytotoxicity of soil residues of EC and G formulations of triallate to wild oats.

Vertical bars represent Tukey's h.s.d. values at 5%.



TRIALLATE
1978
EC
G
TRIALLATE
1979
EC
G
SHOOT DRY WT. (Percent of Control)
45
40
35
30
25
20
15
10
5
0
50
45
40
35
30
25
20
15
10
5
0
0
4
8
12
16
20
WEEKS AFTER SEEDING

Plate 4. Growth of wild oats in post-harvest soil samples taken from plots treated with granular (G) and emulsifiable concentrate (EC) formulations of triallate.

a) untreated control; b) 1.68 kg/ha spring-applied G; c) 1.68 kg/ha fall-applied G; d) 1.68 kg/ha spring-applied EC; e) 1.68 kg/ha fall-applied EC; f) 3.36 kg/ha fall-applied EC.

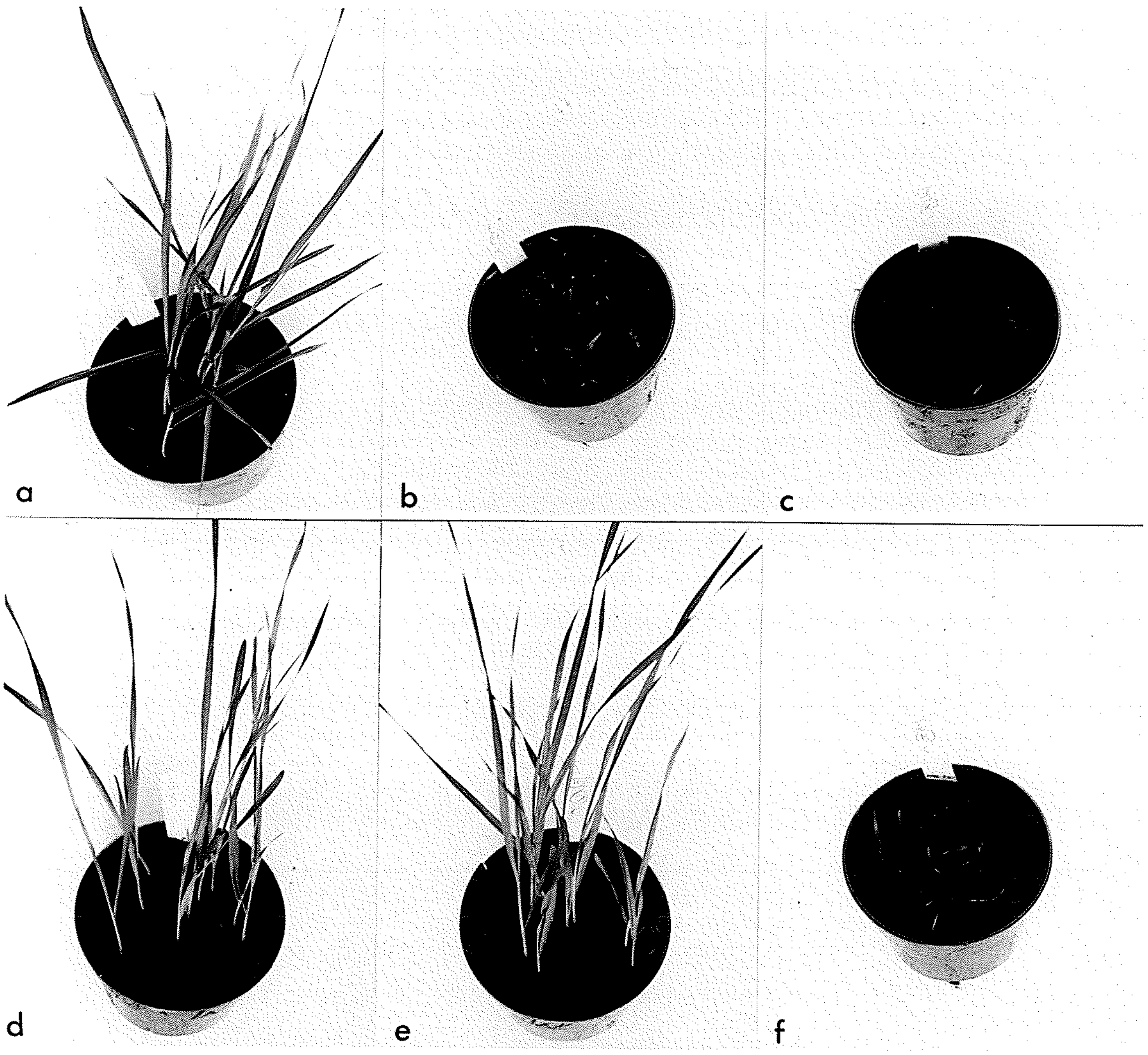

a
b
c
d
e
f

Table 9. Shoot dry weight of wild oats grown in triallate-treated soil that was collected during the 1978 growing season.

| Formulation | Rate[a] | Weeks After Seeding[b] | | |
|---|---|---|---|---|
| | | 0 Week | 6 Weeks | 15 Weeks |
| | (kg/ha) | mg/plant | | |
| Emulsifiable concentrate | 0.0 | 104 a | 112 a | 104 a |
| | 1.68 (S) | 0 b | 13 b | 26 b |
| | 1.68 (F) | 0 b | 4 b | 24 b |
| | 3.36 (F) | 0 b | 0 b | 4 b |
| Granular | 0.0 | 110 a | 110 a | 104 a |
| | 1.68 (S) | 0 b | 6 b | 23 b |
| | 1.68 (F) | 0 b | 2 b | 16 b |
| | 3.36 (F) | 0 b | 0 b | 4 b |

[a] Rates followed by an "S" indicate a spring application while an "F" indicates a fall application.

[b] Shoot dry weights are the mean of four replicates and values followed by the same letter are not significantly different at the 5% level according to Tukey's w value.

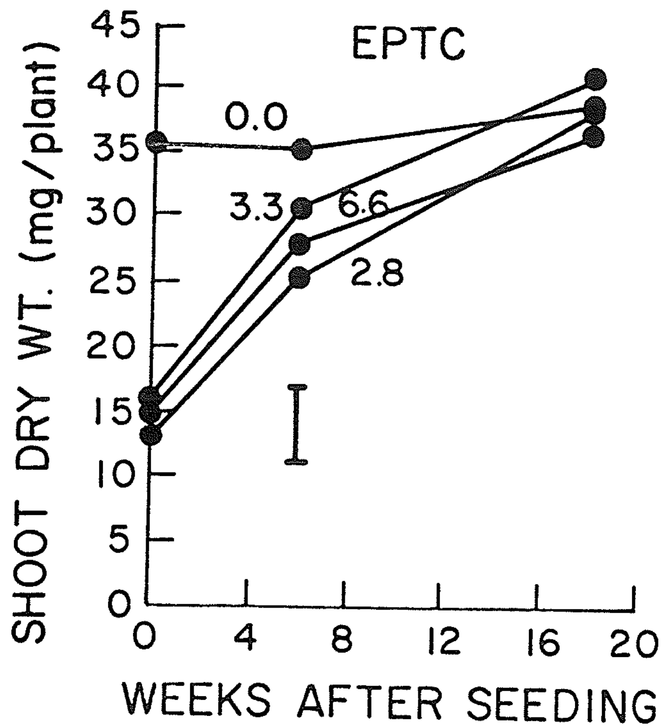
Table 10. Shoot dry weight of wild oats grown in triallate-treated soil that was collected during the 1979 growing season.

| Formulation | Rate[a] | Weeks After Seeding[b] | | |
|---|---|---|---|---|
| | | 0 Week | 6 Weeks | 18 Weeks |
| | (kg/ha) | mg/plant | | |
| Emulsifiable concentrate | 0.0 | 93 a | 95 a | 93 a |
| | 1.68 (S) | 5 e | 18 de | 56 b |
| | 1.68 (F) | 3 e | 3 e | 53 bc |
| | 3.36 (F) | 0 e | 2 e | 11 e |
| Granular | 0.0 | 89 a | 90 a | 88 a |
| | 1.68 (S) | 0 e | 6 e | 32 cd |
| | 1.68 (F) | 0 e | 2 e | 5 e |
| | 3.36 (F) | 0 e | 0 e | 3 e |

[a]Rates followed by an "S" indicate a spring application while an "F" indicates a fall application.

[b]Shoot dry weights are the mean of four replicates and values followed by the same letter are not significantly different at the 5% level according to Tukey's w value.

Figure 7. Phytotoxicity of soil residues of EPTC to yellow foxtail. Vertical bars represent Tukey's h.s.d. values at 5%.


EPTC
0.0
3.3
6.6
2.8
SHOOT DRY WT. (mg/plant)
45
40
35
30
25
20
15
10
5
0
0
4
8
12
16
20
WEEKS AFTER SEEDING

the difference between the two treatments was not significant. None of the EPTC treatments affected shoot dry weight of yellow foxtail when the soil was sampled following harvest of the field plots.

## Discussion

Initial soil concentration at the time of seeding for trifluralin (Figure 1), dinitramine (Figure 2), and triallate (Figures 3 and 4) show that considerably lower levels were found than that expected from the theoretical calculated levels (Appendix Table 11). Results from the fall applications may be explained by herbicidal loss following application and prior to initial soil sampling at the time of seeding. However, this seems unlikely considering that the extracted levels were similar in fall and spring treated plots even though the spring treated plots were sampled within hours after application. Thus, this would indicate that considerable herbicide loss occurred very shortly after application.

For trifluralin, many researchers have reported that volatilization can be a major source of dissipation of the chemical (Swann and Behrens, 1972; Messersmith et al., 1973; Helling, 1976). Generally, it is thought that soil incorporation shortly after application will limit the amount of volatility losses of trifluralin. However, Swann and Behrens (1972) showed that vapours arising from trifluralin treated soil, 16 to 22 days after application, were sufficient to induce shoot growth reduction with proso millet seedlings, indicating that considerable losses due to volatilization of the chemical were still occurring.

In the current study, it is highly probable that the large discrepancies between the amount of extractable chemical and the expected soil concentrations may be the result of losses occurring through volatilization prior to the time of initial soil sampling. Further evidence of this lies in the results obtained with triallate where soil concentrations found in the granular treated plots were more in line with expected soil concentrations while plots treated with the EC formulation showed much lower levels (Figures 3 and 4). Miller and Nalewaja (1976) have shown that vapour losses are greater with the EC formulation than with the granular formulation of triallate. Thus, the difference in vapour loss between the two formulations may explain the difference in the extracted soil concentrations. Furthermore, large vapour losses of trifluralin and dinitramine (which were applied as EC formulations) following application may also account for the differences found between predicted concentrations and extracted values.

Climatic conditions may also have influenced the soil concentrations of trifluralin, dinitramine, and triallate at time of seeding, especially for the fall-applied treatments. The spring of 1979 was much wetter and cooler than that of 1978 (Appendix Table 2 and Appendix Figure 1) and as a result seeding was delayed in 1979. This meant more time passed from time of fall application to seeding for the herbicide to be lost. This delay in sampling may explain some of the differences between the initial levels found in 1978 and 1979. Furthermore, several researchers (Harvey, 1973; Zimdahl and Gwynn, 1977; Savage, 1978) have found that some dinitroanilines, including trifluralin, are less persistent under moist conditions than dry conditions. Thus, the relatively moist conditions of the spring of 1979 may have led to increased herbicide loss compared to the loss in 1978 prior to the initial soil sampling. However, neither of these possibilities would explain the differences encountered between residues detected after spring applications of trifluralin and dinitramine since both were sampled shortly after application.

For triallate, the mean concentrations of the herbicide in the top 5 cm of soil following the spring application of 1.68 kg/ha were very similar at time of seeding during both years of the study with either formulation used. However, when applied in the fall, soil concentrations of triallate at the time of seeding in 1979 were less than half that found in 1978, indicating that considerably more losses occurred in the 1978-79 winter than in the 1977-78 winter. Smith (1975) reported that 45% of the applied triallate was lost during the 1971-72 winter, while 60% was lost during the 1972-73 winter following fall applications of the herbicide. However, in his study, no attempt was made to determine the soil concentration at time of application but he assumed that all of the chemical applied was present in the soil. Regardless, climatic conditions following a fall treatment prior to freeze-up or after spring thaw could greatly influence the extent to which the herbicide persists.

As shown in Figure 1, the persistence of trifluralin in the top 5 cm of soil followed similar patterns in both years of the study, even though initial soil concentrations were different. The fall application at 1.12 kg/ha consistently resulted in higher soil concentrations than the spring treatment at 0.84 kg/ha on each sampling date. Coupled with better yellow foxtail control at the later sampling dates (Figure 5b), the fall application rate may result in carryover levels that could be harmful to susceptible crops. For trifluralin there may be no need to increase application rates when using a fall treatment especially on the soil type used in this study. Webster _et al._ (1978)

found that on Almasippi loamy sand much less applied or residual trifluralin was required for wild oat control than on heavier soils based on $ED_{50}$ values.

Smith (1975, 1979) and Smith and Hayden (1976) reported that on a sandy loam soil under Saskatchewan conditions between 9 and 21% of initial spring-applied trifluralin remained after the growing season. Results of the current study are fairly similar with 11% (29% of initial concentration) and 3% (13% of initial concentration) of the spring-applied trifluralin remaining after harvest in 1978 and 1979, respectively. While this study did not ascertain the amounts lost during the winter months following a fall application, initial trifluralin levels were lower in 1979 than in 1978 indicating that more was lost prior to spring sampling in the second year. Other work has shown that considerable losses of trifluralin could occur over the winter months (Smith, 1979), although the current study shows that soil concentrations were consistently higher in fall-treated plots than in spring-treated ones. In fact, initial soil concentrations show that spring-treated plots had 82 and 65% of the levels found in the fall-treated plots in 1978 and 1979, respectively. Considering that spring treatments of trifluralin had been applied at 75% of the fall rate, these values parallel the differences in application rates. This may indicate that losses over winter are not critical but losses that occur shortly after application may play a major role.

Over the 2 years of this study, dinitramine was the least persistent of the herbicides analyzed in the residue studies. Dinitramine was rapidly dissipated during the 6 weeks following seeding and thereafter, more slowly (Figure 2). On sandy loam soil of a similar type used in this study, Smith (1975) and Pritchard and Stobbe (1979) indicated that dinitramine was less persistent than trifluralin. The work reported here bears this out. The phytotoxicity studies show very little difference in the activity of the fall and spring applications of dinitramine to influence the growth of yellow foxtail as may be expected considering that residual levels were very similar.

Persistence of triallate was inconsistent during the 2 years studied. While initial levels with the fall treatment were lower in 1979 than in 1978, they tended to persist longer. The spring applications of triallate followed the same pattern with the exception that initial soil concentrations were not greatly different in the 2 years. Thus, it appears that conditions were more favourable for degradation of triallate during the 1978 growing season than in 1979. Other work has suggested that increased precipitation may enhance loss of triallate especially in heavy clay and silty clay soils (Smith, 1975).

Studies by Smith on Saskatchewan soils have shown considerable variation in residual levels of triallate in the soil following the growing season. These values have ranged from 6% (Smith and Hayden, 1976) to 20% (Smith, 1970) of the spring-applied chemical in sandy loam soil. Results in the current study reflect a similar carryover to the end of the growing season if expected soil concentrations are used as the initial soil level. However, persistence of triallate based on soil concentrations detected at the time of seeding reflect much higher percentages remaining especially with the granular treatments in the 1979 study.

Phytotoxicity studies with triallate showed that it effectively controlled wild oats except in the post-harvest soil samples collected in 1979 from EC treated plots. While extracted soil concentrations in the post-harvest soil samples are a relatively small percentage of the applied chemical, there was still considerable bioactivity. As was the case with trifluralin, the activity shown by triallate in the post-harvest soil samples may present carryover problems with susceptible crop injury in the year after application on sandy loam soil. This may be especially important with the granular formulation which showed greater persistence on this soil type.

As shown in the phytotoxicity studies, pendimethalin caused the most toxicity to yellow foxtail over the three sampling dates with very little growth occurring even in the post-harvest soil samples. EPTC showed the least toxicity and persistence as considerable foxtail growth occurred in soil samples collected 6 weeks after seeding and no effects were noticeable in post-harvest soil samples. Trifluralin and dinitramine were intermediate in terms of prolonged activity on yellow foxtail.

Savage (1978) found that pendimethalin persisted longer than trifluralin which displayed more persistence than dinitramine when applied at similar rates to moist soil. Based on toxicity to yellow foxtail, the current studies showed a similar pattern although it should be noted that the three herbicides are applied at different rates.

$ED_{50}$ values calculated by Pritchard (1976) indicated that dinitramine was more toxic to sorghum and wild oats than trifluralin. The present study determined that trifluralin showed more toxicity than dinitramine to yellow foxtail in post-harvest soil samples. However, from the data on persistence, trifluralin residues were much higher than dinitramine which likely explains the reversal in relative toxicity.

The possibility remains that yellow foxtail may be more resistant to dinitramine than trifluralin but this difference was not ascertained.

The phytotoxicity studies have shown that EPTC was the least persistent of the herbicides examined and in fact, considerable weed growth occurred in the 6 week soil samples. This correlates well with the results of the field experiments in Chapter II where control of green foxtail was inconsistent and lack of control could probably be ascribed to late germinating seeds which escaped injury after considerable loss of EPTC had occurred. Vapour loss of EPTC through volatilization occurs rapidly after application and incorporation is needed to prevent large losses according to Gray and Weierich (1965). These authors showed that even after incorporation to a depth of 7 cm up to 25% of the applied EPTC was lost within 6 days and as incorporation depth decreased, the amount lost increased. Thus, the amount of EPTC present in the top 5 cm of soil that was sampled 6 weeks after seeding in the present study was likely minimal and may explain the rapid loss in bioactivity shown by increasing yellow foxtail growth.

From the studies on persistence and phytotoxicity of the soil-applied herbicides, the following conclusions can be drawn:

1) At the rates studied, trifluralin, pendimethalin, and triallate carryover in a sandy loam soil may be sufficient to injure susceptible crops the year after application.

2) In sandy loam soils, recommended rates of trifluralin and triallate may be higher than necessary to adequately control susceptible weeds.

3) Carryover of dinitramine and EPTC is not likely to pose problems for subsequent crop selection.

4) Considerable losses of trifluralin, dinitramine, and triallate occurred very shortly after application.

5) Fall applications of trifluralin are more persistent than spring applications.

6) Granular triallate persists at higher soil levels than the EC formulation.

In view of the findings of this Chapter, recommendations on the use of triallate and trifluralin under Manitoba conditions may have to be reviewed.

# CHAPTER IV

# GERMINATION AND GROWTH OF RETRIEVED WEED SEEDS

## Introduction

The use of fall applications of soil-applied herbicides in Western Canada has become common practice to many farmers. Fall applications of chemicals such as triallate (Miller and Nalewaja, 1980), trifluralin (Friesen and Bowren, 1973), and tank mixtures of trifluralin and metribuzin (Betts and Morrison, 1979) have resulted in weed control that is nearly equivalent to similar spring applications. While one would expect herbicide losses to occur prior to spring seeding following a fall application, satisfactory levels of weed control indicate that sufficient chemical remains to effectively control weeds.

Several researchers have found that herbicides can affect germination of seeds. Fawcett and Slife (1975) reported that exposure to EPTC or butylate vapours significantly increased seed germination of common lambsquarters and velvetleaf, while diallate vapours had no effect on weed seeds. Appleby and Brenchley (1968) found that germination of bluegrass and perennial ryegrass was severely reduced when the seeds were exposed to paraquat sprayed at 1.12 kg/ha.

Other researchers have shown that several different herbicides could be absorbed by soybean seed. Rieder _et al._ (1970) found that various herbicides were absorbed by soybean seed at different rates.

Absorption was not directly related to water uptake and would continue after the seeds were imbibed. Similarly, Scott and Phillips (1973) reported that differences existed in the rate and amount of various herbicides absorbed by soybean seed from aqueous solution. In soil, the amount of atrazine and chlorpropham absorbed was greater than that predicted by their perfect sink equation over the first 4 hour period. Over this period of time, the amount of herbicide moved to the seed in imbibed water did not account for the total amount of herbicide absorbed, indicating that mass flow was not the only active force.

The current study was conducted to determine the effects of fall-applied herbicides on germination and seedling growth of buried yellow foxtail and wild oat seed.

## Materials and Methods

### Seed Retrieval

After incorporation of the fall-applied herbicides in 1977 and 1978 (Tables 1 and 2), 5 g of yellow foxtail seed (about 1,500 seeds) were thoroughly mixed into about 1,500 g of the treated soil taken from the top 5 cm of each of the field plots. In the fall of 1978, 38 g of wild oat seed (about 2,000 seeds) were also placed in the plots in the same manner as described for yellow foxtail. The mixture of seed and soil was then placed into a 13 x 30 cm mesh bag made from nylon window screening and placed back into the depression from where the soil had been taken. Bags containing weed seeds were placed into each of the treated plots and in the untreated control plots in each replicate. Seed placement occurred on October 27, 1977 and November 2, 1978.

The bags were retrieved the following spring on May 1. At the time of seed placement, the yellow foxtail seed had 91 and 94% germination in 1977 and 1978, respectively, while the wild oat seed had 86% germination.

Following retrieval of the mesh bags in the spring, the soil was air-dried and separated from the weed seed by briskly rubbing the bag. Plant debris was removed from the seed by screening and the seed was stored for 3 to 10 months at room temperature prior to studies on germination and seedling growth.

Germination and Seedling Growth

Germination tests were conducted on yellow foxtail seed retrieved in the spring of 1977 and 1978. Two samples of 50 seeds from each bag were placed into two 9 cm petri dishes containing 2 mL of distilled water and one 9 cm Whatman #1 filter paper. Tests were conducted in darkness for 2 weeks in a growth cabinet at 15° C and 95 to 100% R.H. The number of germinating seeds was determined 4, 7, and 14 days after initiation of the experiments. After 14 days, five representative seedlings from each petri dish were selected and their root and shoot lengths measured. Thus, for each treatment, 40 seedlings were measured, 10 from each of the four treated plots.

Similar tests were conducted with the wild oat seeds, with the only differences in procedure being that three samples of 25 seeds each were placed into three petri dishes and 4 mL of distilled water were added to each. In total, 300 seeds were tested for each treatment with 75 coming from each of the four field plots. A total of 10 seedlings were selected at random from the three petri dishes and the length of the roots and shoots determined 14 days after initiation of the germination tests.

Seeds retrieved from field plots treated with dinitramine, pendimethalin, and trifluralin were included in one experiment. The experimental design was a randomized complete block with four replicates. Seeds retrieved from field plots treated with EPTC and the EC and granular formulations of triallate were included in a separate experiment and treated in a similar manner. Each experiment included seeds retrieved from untreated field plots. The experiments were repeated twice, with the final results expressed as the average of the two tests.

## Growth Room Studies

Studies were conducted in the growth room with seeds of yellow foxtail and wild oats to determine the ability of the seedling to outgrow the initial effects of the herbicides on root and shoot growth. Seeds included in these experiments came from a single field plot. These were selected on the basis of good germination and desirable seedling injury.

Twenty seeds of yellow foxtail and 25 seeds of wild oats retrieved from field plots treated with dinitramine, pendimethalin, and trifluralin were planted in a 10 cm diameter pot to a depth of 1.5 and 2.5 cm, respectively. The soil was an Almasippi very fine sandy loam. Plants were grown under a 16 h photoperiod with a $22^{\circ}$ C/$16^{\circ}$ C day/night temperature regime, 50 to 60% R.H., and a light intensity of 255 $\mu Em^{-2}s^{-1}$. The pots were watered regularly to maintain soil moisture between 50 and 100% field capacity. The number of plants that emerged in each pot was counted periodically. The shoots were harvested 21 days after emergence of the untreated controls and dried in an oven at 80° C for 48 h. The dry material was weighed and the results expressed as dry weight per shoot.

The two weed species were included in separate experiments with each test being arranged in a randomized complete block design with six replicates. Each experiment was duplicated and the results are expressed as the average of the two tests.

## Histological Studies With Yellow Foxtail

Seeds of yellow foxtail retrieved from field plots treated in the fall with dinitramine, pendimethalin, and trifluralin as previously reported, were placed in petri dishes in a growth cabinet at 15° C and 95 to 100% R.H. for 10 days. Small sections (2 to 3 mm) were dissected from the region of the coleoptile node of the seedlings and fixed in a 0.025 M phosphate-buffered 5% glutaraldehyde solution (pH 6.8) under vacuum. The samples were then washed four times in cold 0.025 M phosphate buffer (pH 6.8) and placed into a 2% aqueous solution of osmium tetroxide. Following this post-fixation process, the tissue segments were washed twice in phosphate buffer and three times in distilled water prior to dehydration.

Dehydration of the tissue was achieved by passing it through a graded ethanol series: 10, 20, 25, 50, 75, 90, 95, and 100% ethanol for 15 minutes each. The tissue was washed a second time with 100% ethanol prior to infiltration. The dehydrated tissue was infiltrated with a 50-50 mixture of ethanol and Spurr's resin (Spurrs, 1969) overnight and then transferred into pure Spurr's resin. The resin was changed twice over 2 days before polymerization at 70° C.

Longitudinal and tranverse sections were cut with glass knives on a Porter-Blum JB-4 microtome. The 2 $\mu$m thick sections were mounted on glass slides and stained with 0.1% toluidine blue O in 1% sodium borate for 1 minute and then rinsed in distilled water followed by a second rinse in 95% ethanol. The sections were then mounted and examined with a conventional bright-field microscope.

## Results

### Germination and Seedling Growth

The percent germination of yellow foxtail seeds retrieved in the spring from plots treated in the previous fall with dinitramine, pendimethalin, and trifluralin is presented in Table 11 and with EPTC and the EC and granular formulations of triallate in Table 12. None of the herbicides significantly affected percent germination of the yellow foxtail seeds. Seeds retrieved in the spring of 1978 showed a greater reduction in percent germination relative to the percent germination at time of seed placement compared to the seeds retrieved in 1979. This was not apparent 4 days after initiation of the germination tests but was very evident after 14 days. Final counts showed that about half as many seeds germinated in 1978 than in 1979.

Fourteen days after initiation of the germination tests, there was no effect on either root or shoot growth of seedlings grown from seeds retrieved from field plots treated with EPTC or triallate (Table 13). All herbicide treatments resulted in a slight reduction in shoot length compared to the untreated control but this was not significant.

The effects of dinitramine, trifluralin, and pendimethalin on shoot and root lengths of yellow foxtail seedlings are shown in Figure 8 (1978) and Figure 9 (1979). With seed retrieved in the spring of 1978, all herbicides except dinitramine at 0.84 kg/ha a.i. significantly

Table 11. Percent germination of yellow foxtail seeds retrieved in the spring from plots treated in the previous fall with three dinitroaniline herbicides.

| Treatment | Applied field dosage | Percent Germination[a] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Day 4 | | Day 7 | | Day 14 | |
| | | 1978 | 1979 | 1978 | 1979 | 1978 | 1979 |
| | (kg/ha) | % | | | | | |
| Untreated | 0 | 29 | 33 | 36 | 62 | 42 | 79 |
| Dinitramine | 0.84 | 27 | 24 | 34 | 60 | 39 | 81 |
| Dinitramine | 1.68 | 30 | 29 | 39 | 65 | 44 | 77 |
| Pendimethalin | 3.0 | 32 | 30 | 44 | 60 | 49 | 77 |
| Pendimethalin | 4.5 | 31 | 29 | 38 | 63 | 44 | 79 |
| Trifluralin | 1.12 | 34 | 35 | 40 | 73 | 42 | 83 |
| Trifluralin | 2.24 | 34 | 35 | 39 | 71 | 42 | 79 |
| | | NSF | NSF | NSF | NSF | NSF | NSF |

[a]Values for percent germination are the average of two trials with 400 seeds tested for each treatment in each trial.

Table 12. Percent germination of yellow foxtail seeds retrieved in the spring from plots treated in the previous fall with EPTC and emulsifiable (EC) and granular (G) formulations of triallate.

| Treatment | Applied field dosage | Percent Germination[a] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Day 4 | | Day 7 | | Day 14 | |
| | | 1978 | 1979 | 1978 | 1979 | 1978 | 1979 |
| | (kg/ha) | % | | | | | |
| Untreated | 0 | 36 | 30 | 40 | 70 | 43 | 80 |
| EPTC | 3.3 | 35 | 32 | 40 | 66 | 47 | 78 |
| EPTC | 6.6 | 34 | 34 | 38 | 74 | 41 | 84 |
| Triallate EC | 1.68 | 34 | 28 | 38 | 67 | 40 | 75 |
| Triallate EC | 3.36 | 31 | 36 | 36 | 71 | 40 | 82 |
| Triallate G | 1.68 | 34 | 34 | 38 | 66 | 42 | 78 |
| Triallate G | 3.36 | 32 | 32 | 36 | 64 | 39 | 77 |
| | | NSF | NSF | NSF | NSF | NSF | NSF |

[a]Values for percent germination are the average of two trials with 400 seeds tested for each treatment in each trial.

Table 13. The effects of fall applications of EPTC and triallate on shoot and root lengths of yellow foxtail retrieved in the spring of 1978 and 1979.

| Treatment | Applied field dosage | Shoot Length[a] 1978 | Shoot Length[a] 1979 | Root Length[a] 1978 | Root Length[a] 1979 |
|---|---|---|---|---|---|
| | (kg/ha) | mm | mm | mm | mm |
| Untreated | 0 | 47.9 | 35.0 | 24.8 | 12.9 |
| EPTC | 3.3 | 46.2 | 32.0 | 23.6 | 14.2 |
| EPTC | 6.6 | 46.6 | 30.8 | 23.9 | 14.0 |
| Triallate EC | 1.68 | 47.0 | 33.7 | 23.8 | 17.1 |
| Triallate EC | 3.36 | 45.4 | 33.3 | 24.2 | 13.9 |
| Triallate G | 1.68 | 46.6 | 34.2 | 24.4 | 11.8 |
| Triallate G | 3.36 | 46.2 | 33.7 | 24.0 | 12.6 |
| | | NSF | NSF | NSF | NSF |

[a]Shoot length and root length were determined 14 days after initiation of germination tests. Shoot and root lengths are the average of two trials with 40 seedlings measured for each treatment in each trial.

Figure 8. The effects of fall applications of dinitramine, trifluralin, and pendimethalin on shoot and root lengths of yellow foxtail retrieved in the spring of 1978.

Vertical bars represent Tukey's h.s.d. values at 5%.

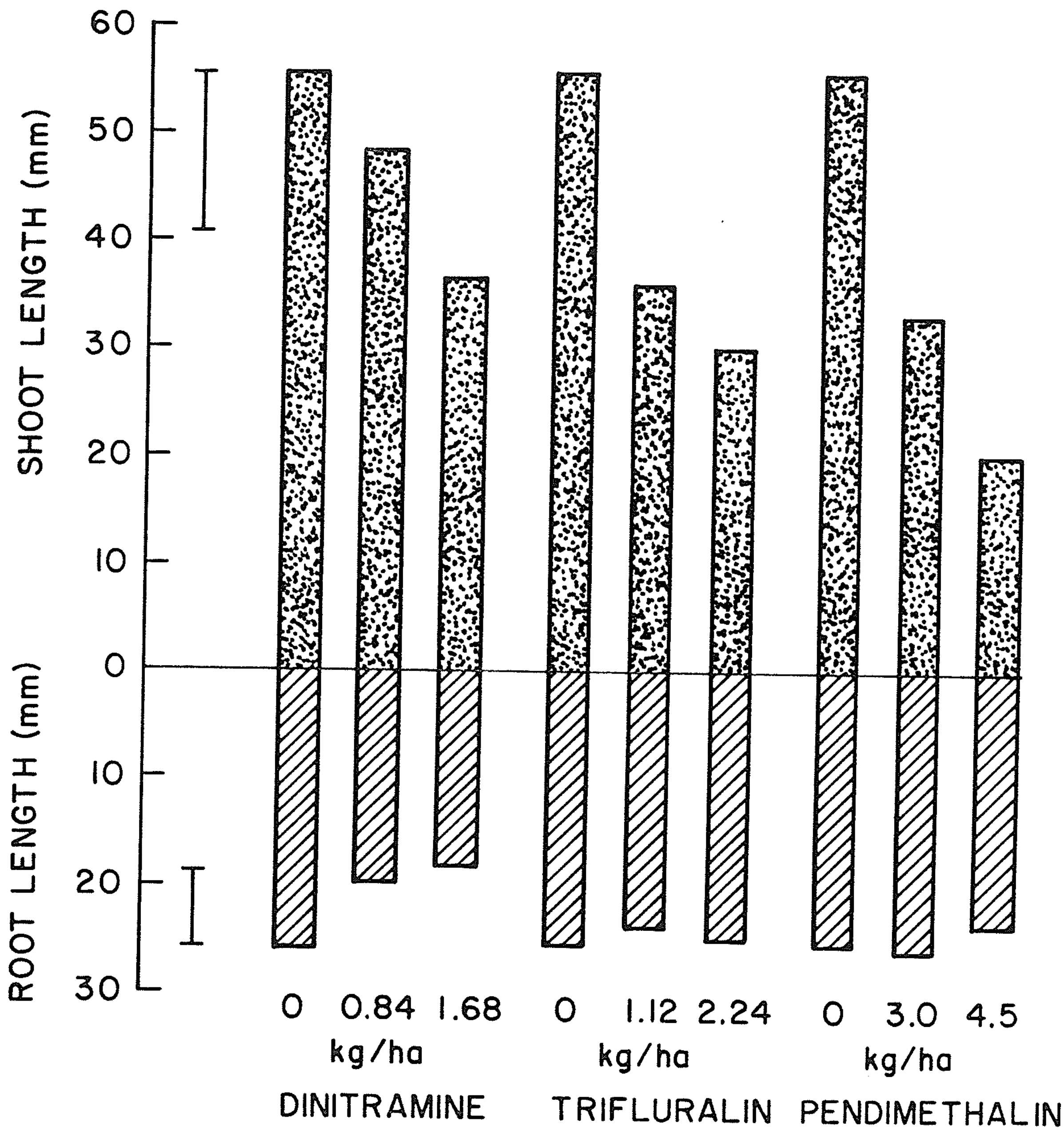
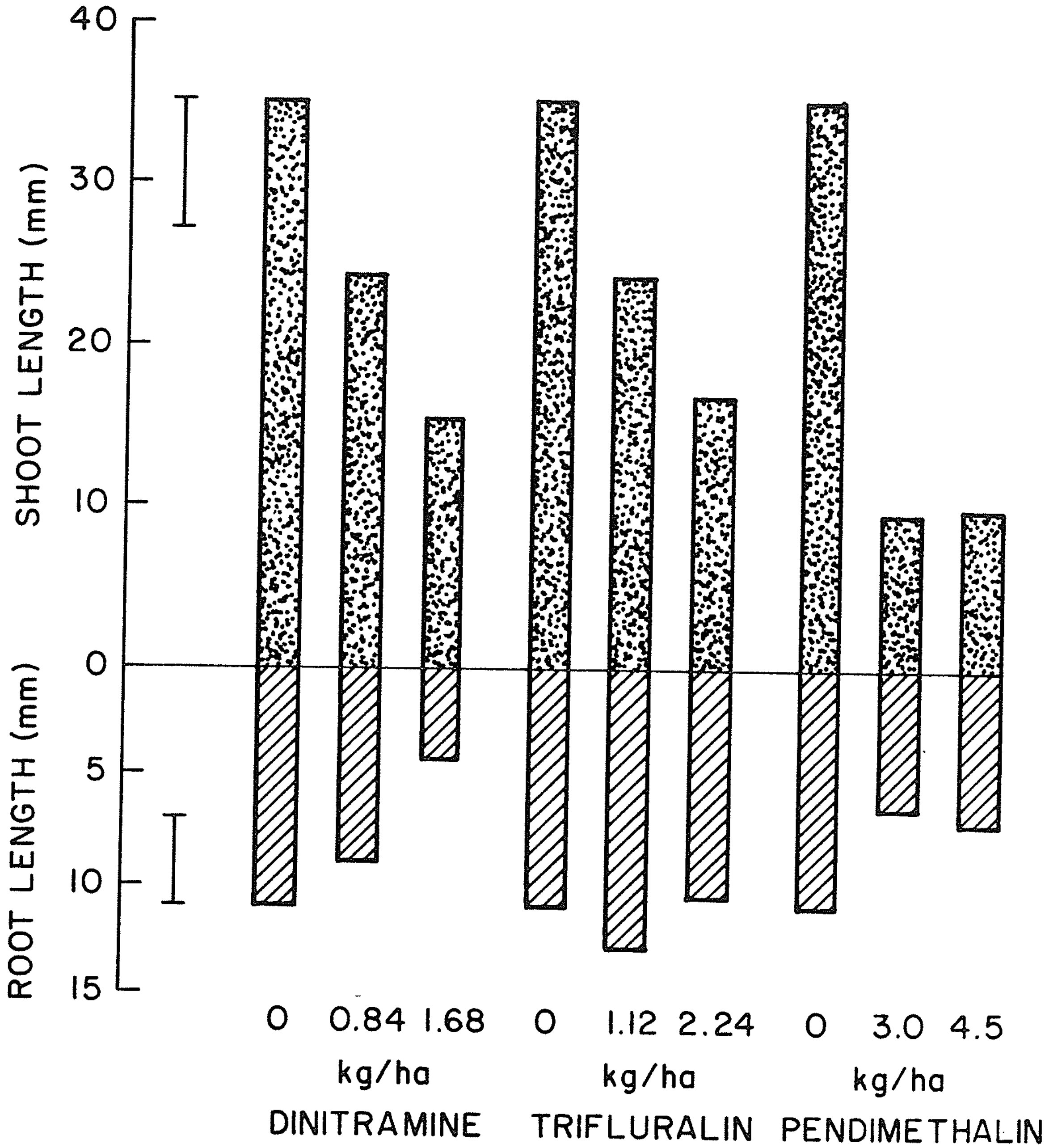

60
50
40
30
20
10
0
10
20
30
SHOOT LENGTH (mm)
ROOT LENGTH (mm)
0 0.84 1.68
kg/ha
DINITRAMINE
0 1.12 2.24
kg/ha
TRIFLURALIN
0 3.0 4.5
kg/ha
PENDIMETHALIN

Figure 9. The effects of fall applications of dinitramine, trifluralin, and pendimethalin on shoot and root lengths of yellow foxtail retrieved in the spring of 1979.

Vertical bars represent Tukey's h.s.d. values at 5%.



40
30
20
10
0
5
10
15
SHOOT LENGTH (mm)
ROOT LENGTH (mm)
0
0.84
1.68
0
1.12
2.24
0
3.0
4.5
kg/ha
kg/ha
kg/ha
DINITRAMINE
TRIFLURALIN
PENDIMETHALIN

reduced shoot lengths compared to the untreated seedlings. All herbicide treatments significantly reduced shoot lengths of yellow foxtail seedlings from seeds retrieved in the spring of 1979.

Typical injury symptoms were swelling of the mesocotyl just below the coleoptile node of the seedling as seen in Plate 5. This was first apparent about 7 days after initiation of the germination tests. The mesocotyl failed to elongate to the same length as in the untreated seedlings. This resulted in the reduction in total shoot length. Of the herbicides tested, trifluralin resulted in the least swelling.

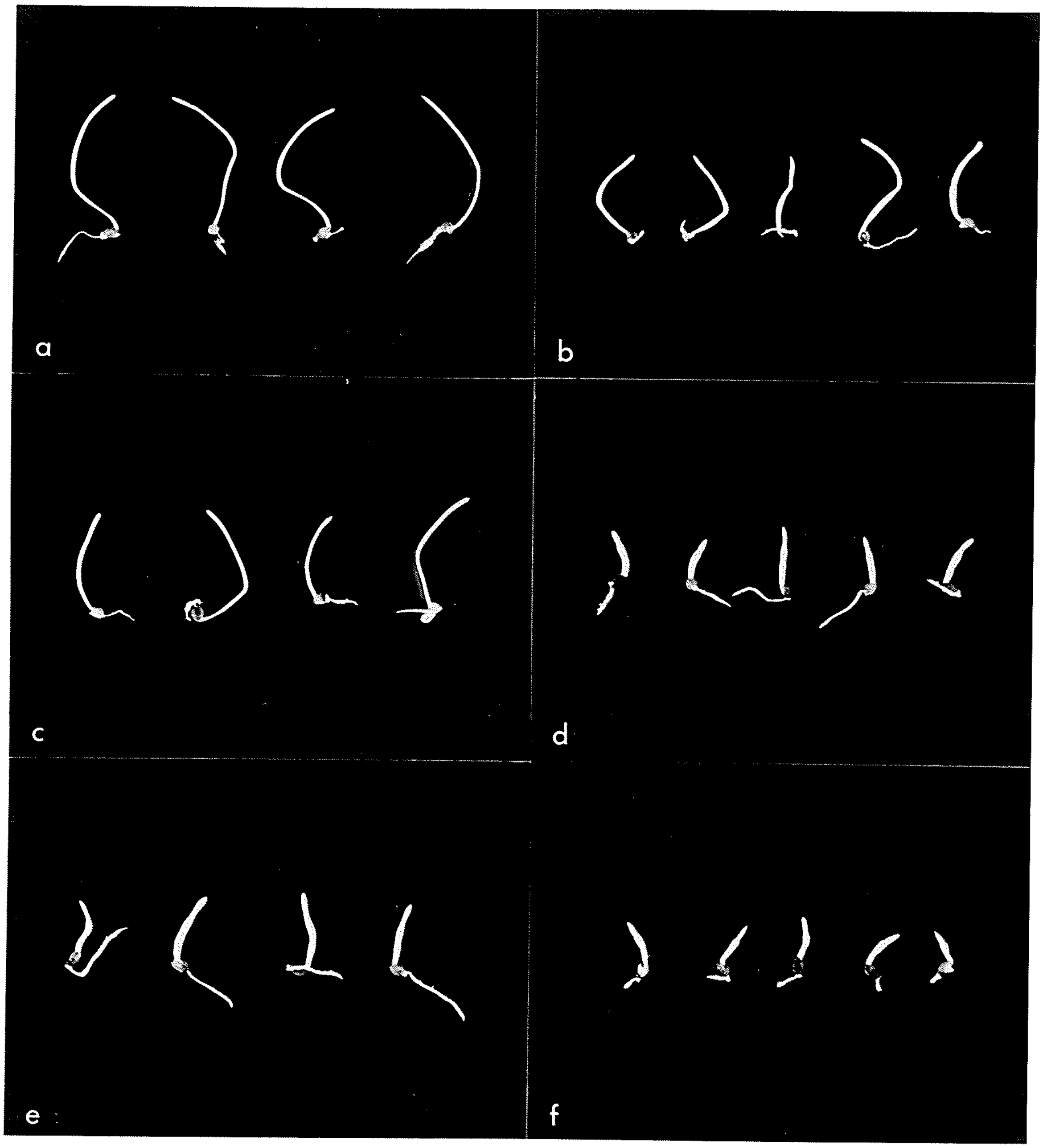
Pendimethalin treatments resulted in the greatest reduction in shoot length of yellow foxtail seedlings in both years of the study. From seeds retrieved in the spring of 1978, dinitramine had the least effect on yellow foxtail shoot length. However, in 1979 both dinitramine and trifluralin reduced shoot lengths to the same degree at both the recommended commercial application rates and twice these rates.

The effects of the dinitroaniline herbicides on root length of yellow foxtail were not consistent in the 2 years of the study as seen in Figures 8 and 9. Only dinitramine at 1.68 kg/ha significantly reduced root lengths compared to the untreated yellow foxtail seedlings in 1978. In 1979, the same dinitramine treatment and pendimethalin at 3.0 and 4.5 kg/ha significantly reduced root lengths of yellow foxtail seedlings when compared to untreated seedlings. Obvious morphological aberrations were not associated with the root length reduction.

In similar studies with wild oat seeds retrieved in the spring of 1979, EPTC and granular and EC formulations of triallate had no effect on percent germination, shoot length, or root length after 14 days

Plate 5. Morphological injury symptoms on developing yellow foxtail seedlings grown from seed retrieved from fall-treated field plots.

a) untreated control; b) 2.24 kg/ha trifluralin; c) 0.84 kg/ha dinitramine; d) 1.68 ha/ha dinitramine; e) 3.0 kg/ha pendimethalin; f) 4.5 kg/ha pendimethalin.


a
b
c
d
e
f

(Table 14). The effect of fall applications of dinitramine, pendimethalin, and trifluralin on wild oat seeds retrieved in the spring of 1979 is reported in Table 15. None of the herbicides significantly affected percent germination although all herbicide treatments appeared to enhance germination of wild oats. Subsequent seedling growth was affected by some of the herbicides. Dinitramine and pendimethalin at both rates significantly reduced shoot length compared to the untreated seedlings. Dinitramine at 0.84 and 1.68 kg/ha a.i. and pendimethalin at 4.5 kg/ha a.i. also significantly reduced root length of wild oats. Injury symptoms were similar to those observed with yellow foxtail. No visible morphological aberrations were associated with the root length reductions.

Growth Room Studies

Tables 16 and 17 report emergence and growth of yellow foxtail and wild oat seeds sown into untreated soil following spring retrieval from the field plots treated in the fall with dinitramine, pendimethalin, and trifluralin. Emergence of yellow foxtail tended to be less than expected from seeds retrieved from the field plots treated with the three herbicides. However, a Chi-Square test for independence showed no significant differences for any of the treatments. Emergence of wild oats was significantly greater than expected for all treatments except trifluralin at 1.12 kg/ha according to the Chi-Square test for independence at the 1% level (Table 17).

Both rates of dinitramine significantly reduced shoot dry weight of yellow foxtail and wild oats compared to the untreated controls. Pendimethalin and trifluralin at both rates also significantly reduced shoot dry weights of yellow foxtail with no differences occurring between the three herbicides.

Table 14. The effects of fall applications of EPTC and triallate on percent germination and shoot and root lengths of wild oats retrieved in the spring of 1979.

| Treatment | Applied field dosage | Percent germination[a] | Shoot length[b] | Root length[b] |
|---|---|---|---|---|
| | (kg/ha) | | mm | |
| Untreated | 0.0 | 39.5 | 35.0 | 30.6 |
| EPTC | 3.3 | 34.2 | 34.7 | 30.2 |
| EPTC | 6.6 | 20.8 | 33.1 | 30.7 |
| Triallate EC | 1.68 | 35.8 | 34.9 | 29.7 |
| Triallate EC | 3.36 | 33.0 | 36.2 | 29.5 |
| Triallate G | 1.68 | 23.8 | 35.0 | 30.0 |
| Triallate G | 3.36 | 26.8 | 35.6 | 31.0 |
| | | NSF | NSF | NSF |

[a]Percent germination is the average from two trials with 300 seeds tested for each treatment in each trial.

[b]Root and shoot lengths were measured 14 days after initiation of germination tests. Values are the averages from two trials, with 40 seedlings measured for each treatment of each trial.

Table 15. The effects of fall applications of dinitramine, pendimethalin, and trifluralin on percent germination and shoot and root lengths of wild oats retrieved in the spring of 1979.

| Treatment | Applied field dosage | Percent germination[a] | Shoot length[b] | Root length[b] |
|---|---|---|---|---|
| | (kg/ha) | | mm | mm |
| Untreated | 0.0 | 22.2 | 35.8 a | 36.4 ab |
| Dinitramine | 0.84 | 35.1 | 27.8 b | 23.9 c |
| Dinitramine | 1.68 | 30.5 | 14.8 d | 16.4 d |
| Pendimethalin | 3.0 | 37.9 | 24.2 bc | 31.0 bc |
| Pendimethalin | 4.5 | 33.0 | 22.0 c | 24.1 c |
| Trifluralin | 1.12 | 28.2 | 34.0 a | 43.0 a |
| Trifluralin | 2.24 | 29.9 | 21.6 c | 38.8 a |
| | | NSF | | |

[a]Percent germination is the average of two trials with 300 seeds tested for each treatment in each trial.

[b]Shoot lengths and root length were determined 14 days after initiation of germination tests. Shoot and root lengths are the average of two trials, with 40 seedlings measured for each treatment of each trial. Values followed by the same letter within a column are not significantly different at the 5% level according to Duncan's Multiple Range Test.

Table 16. Emergence and growth of yellow foxtail from seeds retrieved in the spring of 1979 following fall applications of dinitramine, pendimethalin, and trifluralin.

| Treatment | Applied field rate | Percent germination | Expected emergence[a] | Actual emergence[a] | Shoot dry weight[b] |
|---|---|---|---|---|---|
| | (kg/ha) | | — no. plants/pot | — | (mg/plant) |
| Untreated | 0.0 | 75 | 15.0 | 15.2 | 26.3 a |
| Dinitramine | 0.84 | 82 | 16.3 | 14.0 | 20.3 b |
| Dinitramine | 1.68 | 82 | 16.4 | 13.8 | 22.3 b |
| Pendimethalin | 3.0 | 80 | 16.0 | 12.1 | 21.1 b |
| Pendimethalin | 4.5 | 80 | 16.1 | 14.4 | 21.0 b |
| Trifluralin | 1.12 | 84 | 16.8 | 14.6 | 20.0 b |
| Trifluralin | 2.24 | 84 | 16.7 | 15.1 | 21.0 b |

[a]Expected emergence is the product of percent germination and the number of seeds planted (20). Actual emergence is the average of six replicates.

[b]Shoot dry weights followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

Table 17. Emergence and growth of wild oats from seeds retrieved in the spring of 1979 following fall applications of dinitramine, pendimethalin, and trifluralin.

| Treatment | Applied field rate | Percent germination | Expected emergence[a] | Actual emergence[a] | Shoot dry weight[b] |
|---|---|---|---|---|---|
| | (kg/ha) | | no. plant/pot | | (mg/plant) |
| Untreated | 0.0 | 23 | 5.8 | 8.9 | 57.1 a |
| Dinitramine | 0.84 | 34 | 8.6 | 13.5 | 37.4 b |
| Dinitramine | 1.68 | 36 | 9.1 | 12.9 | 39.8 b |
| Pendimethalin | 3.0 | 26 | 6.6 | 12.3 | 38.5 b |
| Pendimethalin | 4.5 | 23 | 5.8 | 8.1 | 49.0 ab |
| Trifluralin | 1.12 | 14 | 3.5 | 4.1 | 55.4 a |
| Trifluralin | 2.24 | 26 | 6.6 | 11.9 | 39.0 b |

[a]Expected emergence is the product of percent germination and the number of seeds planted (25). Actual emergence is the average of six replicates.

[b]Shoot dry weights followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

Histological Studies With Yellow Foxtail

Longitudinal and transverse sections taken through the mesocotyl near the coleoptile node of 10-day-old yellow foxtail seedlings are shown in Plate 6. Seedlings grown from seed taken from field plots treated with dinitramine and pendimethalin showed considerable radial expansion of the cortical cells compared to untreated seedlings. With pendimethalin at either rate tested, the cells in or near the epidermis are most affected while considerable hypertrophy was found throughout the entire cortical area in dinitramine-treated seedlings.

Longitudinal sections of untreated seedlings show orderly files of cells in the mesocotyl of yellow foxtail which were also present in the trifluralin-treated material. The orderly files were disrupted in dinitramine- and pendimethalin-treated seedlings and the cortical cells were greatly enlarged longitudinally as well as radially.

In both treated and untreated sectioned material, there was no evidence of mitotic figures. However, the material was obtained from 10-day-old seedlings by which time mitotic division in the mesocotyl may have been completed. Vascular damage did not seem apparent although the radially enlarged cells occurring in the pendimethalin and dinitramine-treated material could conceivably crush the vascular system found in all seedlings.

## Discussion

None of the herbicides tested significantly affected percent germination of yellow foxtail and wild oats retrieved from fall-treated plots although the dinitroaniline herbicides showed some enhancement of wild oats germination. Germination of yellow foxtail seed was much higher in the second year of the study than in the first. In both years, seed samples were collected on May 1, but spring conditions were quite different

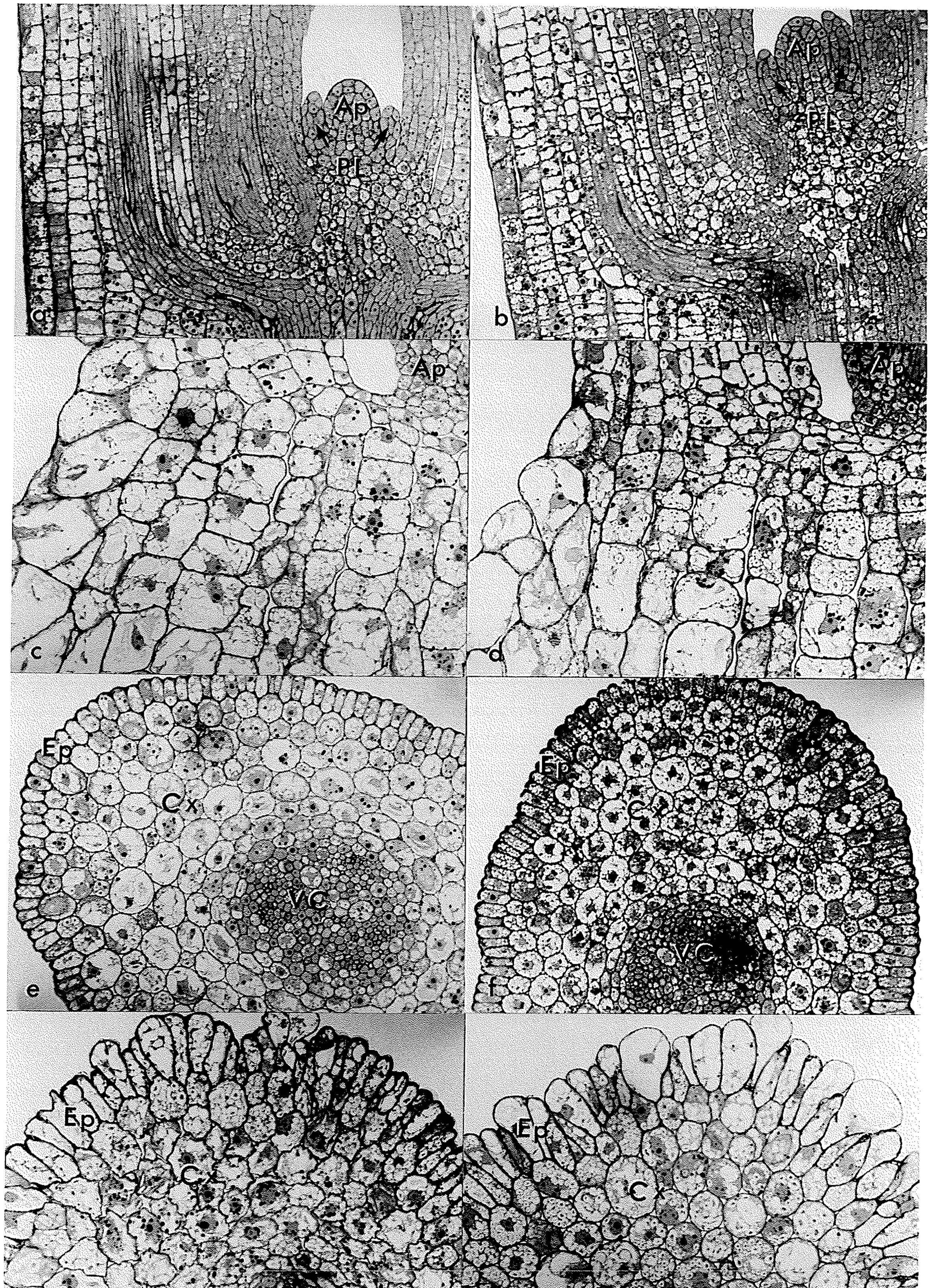
Plate 6. Longitudinal and transverse sections taken through the coleoptile node region of 10-day-old yellow foxtail seedlings.

Ap, apical meristem; Cx, cortex; Ep, epidermis; PL, primordial leaves; VC, vascular cylinder.

a-d) longitudinal sections; e-h) transverse sections

a) untreated control; b) 2.24 kg/ha trifluralin; c) 1.68 kg/ha dinitramine; d) 4.5 kg/ha pendimethalin; e) untreated control; f) 2.24 kg/ha trifluralin; g) 1.68 kg/ha dinitramine; h) 4.5 kg/ha pendimethalin.

All X160.



Ap
PL
a
b
Ap
c
d
Ep
Cx
VC
e
f
Ep
Cx
VC
g
Ep
C
h

in the 2 years (Appendix Figure 1). The spring of 1978 was warmer than the spring of 1979, although both had temperatures below the long term average for Graysville, Manitoba. Consequently, some of the yellow foxtail seeds had germinated before they were retrieved early in 1978 which reduced the number of viable seeds remaining.

In the second year of the study, percent germination of retrieved yellow foxtail seed was reduced to about 80 from 94% when the samples were spiked into the soil the previous fall. These findings are similar to the results reported by Dawson and Bruns (1975) where yellow foxtail seeds lost 8 to 18% germination over the winter period. Wild oat seed retrieved in the spring of 1979 showed a sharp decline from 86 to about 30% germination which is similar to the results found by Banting (1965).

The germination studies reported here show no effect on percent germination although some researchers have found that certain herbicides may affect germination of some weed seeds. For example, Fawcett and Slife (1975) reported that germination of common lambsquarters and velvetleaf was significantly increased following exposure to vapours of EPTC or butylate at concentrations of 1.2 and 2.4 g/mL. At the same concentrations, diallate vapours had no effect on germination of weed seeds.

From the results reported in Figures 8 and 9 and Table 15, it seems apparent that the dinitroaniline herbicides tested are capable of affecting the growth of seedlings from retrieved yellow foxtail and wild oat seed even though they did not interfere with percent germination. This study did not attempt to determine whether the herbicide was actually absorbed into the caryopsis or adsorbed to the lemma and palea surrounding the caryopsis or to very fine soil particles adhering to the seeds even after they had been rubbed clean. However, if the herbicide molecules were absorbed into the caryposis then there would be a greater likelihood that they might affect germination than if they were simply in close proximity to the seed. Furthermore, injury to the seedlings was not apparent until about 7 days after germination. This may indicate that the herbicide was absorbed into the developing shoot well after germination of the seed. The developing shoot is thought to be the major site of absorption of the dinitroaniline herbicides as discussed by Parka and Soper (1977).

The swelling of the shoot below the coleoptile node shown in Plate 5 is similar to trifluralin injury symptoms observed on corn by Schultz et al. (1968) and on wild oats by Billet and Ashford (1978). From the histological studies done as part of the present study, the swelling resulted from radial and longitudinal expansion of cells present in this region as seen in Plate 6. The more prominent swelling observed in yellow foxtail seedlings following retrieval from plots treated with dinitramine and pendimethalin was the result of more dramatic cellular expansion.

Coupled with the swelling symptom was a decrease in shoot length of yellow foxtail and wild oat seedlings, primarily in the mesocotyl region. It can be postulated that the decrease in shoot length may be due to either a disruption of mitosis or cell elongation or both. During the period of shoot emergence from the soil, wild oat and yellow foxtail shoots elongate through the soil as a result of mitotic division and cellular enlargement in the mesocotyl portion of the shoot. Blockage of cell division would limit shoot elongation through a reduction in the number of cells available for expansion and thus decrease total shoot length as seen in Figures 8 and 9. Dinitroaniline herbicides have been shown in previous studies to specifically disrupt mitotic activity (Parka and Soper, 1977).

Trifluralin has been reported to affect root growth by many researchers. Schultz _et al._ (1968) reported reductions of root and shoot lengths of corn seedlings by trifluralin as well as radial expansion of cortical cells and the presence of multinucleate cells in the meristematic regions after seedlings were germinated in 5 mg/L trifluralin solution for 3.5 days. Cotton, safflower, and watergrass roots showed an increase in the amount of radial expansion near the root tip following treatment with $10^{-6}$ M trifluralin in studies conducted by Bayer _et al._ (1967). Working with corn and wheat roots, Lignowski and Scott (1971) found that trifluralin at $4 \times 10^{-6}$ M reduced root length and induced radial swelling of the root tip through the region of cell elongation. In the present studies with retrieved weed seeds, there was no evidence of swelling of root tips from the dinitroaniline herbicides. However, as seen in Figures 8 and 9, yellow foxtail seedlings grown from seeds retrieved from field plots treated with 1.68 kg/ha a.i. dinitramine in both years and with 4.5 kg/ha a.i. pendimethalin in 1979, showed significant root length reductions compared to untreated seedlings. These two herbicides also reduced root lengths of wild oat seedlings as reported in Table 15. The failure to produce the typical root tip swelling characteristic of dinitroaniline herbicides may be the result of low herbicidal levels and a preference for absorption through the coleoptile node.

It is apparent that the dinitroaniline herbicides were affecting seedling growth, especially shoot elongation, of the retrieved wild oat and yellow foxtail seeds. From the results reported in Tables 16 and 17, the phytotoxic effects were not sufficient for seedling mortality. The injured seedlings were still capable of producing viable plants even though they may have been less vigorous as shown by significant shoot dry weight reductions in most cases. There was a reduction in the number of yellow foxtail plants that emerged when comparing expected to actual emergence although this difference was not statistically significant. The significant reductions in shoot length of yellow foxtail may have led to the reductions in expected emergence. The increase in the number of wild oat seedlings that emerged compared to the expected emergence may be the result of a gradual loss of dormancy through storage at room temperature as noted by Banting (1965).

The differences seen in the toxicities of dinitramine, pendimethalin, and trifluralin to yellow foxtail and wild oats may be related to rates of application, amounts of absorption/adsorption, and inherent toxicities of these herbicides. The morphological effects were more pronounced with pendimethalin but it was applied at the highest rates. Trifluralin had the least effect on yellow foxtail and wild oat seedlings even though it was applied at higher rates than dinitramine.

Triallate, in either formulation, and EPTC showed little or no effect on germination and seedling growth of yellow foxtail and wild oats (Tables 12, 13, and 14). Billet and Ashford (1978) reported that triallate granules incorporated to a depth of 5 cm, reduced mesocotyl length of wild oats while trifluralin induced reductions in both mesocotyl and coleoptile length. Furthermore, Banting (1970) reported shoot inhibition of wild oats by triallate at concentrations that had no effect on mitosis. From the present studies, it seems apparent that triallate and EPTC were not taken up in sufficient quantities by overwintered seeds which would induce phytotoxic responses by wild oats and yellow foxtail while dinitramine, pendimethalin, and trifluralin were.

The results of this chapter on germination and growth of retrieved weed seeds can be summarized as follows:

1) None of the herbicides affected percent germination of yellow foxtail and wild oat seeds.

2) Seeds of yellow foxtail and wild oats retrieved in the spring from fall-treated plots had taken up sufficient quantities of trifluralin, dinitramine, and pendimethalin to induce morphological injury symptoms on germinating seedlings.

3) The quantity of herbicide taken up was insufficient to result in weed seedling mortality when the plants were grown from seed in untreated soil.

# SUMMARY AND CONCLUSIONS

The field experiments showed that fall applications of trifluralin, dinitramine, pendimethalin, triallate, and EPTC result in improved crop tolerance and with the exception of EPTC, levels of weed control that are equivalent to spring treatments. While improved crop tolerance following a fall application did not always result in subsequent yield improvement, whenever better crop tolerance was combined with equivalent weed control to a spring treatment, seed yields were higher with a fall treatment than a spring treatment.

The field studies have also indicated the need for broad spectrum weed control when growing crops such as flax and rapeseed. Applications of triallate which only controls wild oats allowed other weed species such as green foxtail to compete freely with the crop.

The studies on persistence showed that considerable losses of trifluralin, triallate, and dinitramine applied as emulsifiable concentrate formulations, occurred very shortly after application, suggesting that volatilization is an important factor in herbicide dissipation. Initial losses of triallate were reduced substantially when the herbicide was applied as a granular formulation.

These studies have also shown that fall applications of trifluralin at 1.12 kg/ha persisted at higher levels than a spring treatment at 0.84 kg/ha and may result in carryover problems on a sandy loam soil. Considering that other research (Webster _et al._, 1978) has shown less trifluralin is required for wild oat control on sandy loam soil, a re-evaluation of application rates may be desirable.

The results of the persistence studies with granular and emulsifiable concentrate formulations of triallate have shown that the granular product persists at higher levels than the EC formulation. Coupled with the results from the phytotoxicity studies, carryover of triallate, especially from granular formulations, may present injury problems to susceptible crops.

Dinitramine and EPTC are unlikely to present carryover problems as the phytotoxicity studies have shown that they have little phytotoxic activity by the end of the growing season. Conversely, of the herbicides studied, pendimethalin was shown to have the most bioactivity at the end of the growing season and injury to susceptible crops is a distinct possibility, especially at the application rates used in this study.

The studies on retrieved weed seeds have shown that none of the herbicides tested affected percent germination of wild oats and yellow foxtail seed. However, the dinitroanilines markedly affected shoot growth of developing seedlings, suggesting uptake of the herbicide prior to commencement of germination. While the shoot injury was insufficient for seedling mortality when grown in untreated soil, further uptake of herbicide during emergence from treated soil would likely produce the desirable effects. Thus, uptake of herbicides by weed seeds in the soil prior to germination may partially explain the adequate levels of weed control seen with fall applications of soil-applied herbicides.

## Recommendations for Future Research

While the current study has resulted in several important findings, considerably more exhaustive studies in this area of research are required. Studies on other soil types in Manitoba should be conducted to assess the efficacy of fall and spring applications of soil-applied herbicides. The current study has indicated that some herbicides can be adsorbed by wild oats and yellow foxtail seed in the soil prior to germination. However, other work is necessary to investigate other weed species and to determine more precisely the nature of adsorption and its influence on early seedling growth.

In view of the findings of this study, considerably more research in Manitoba and the prairies must be conducted to investigate problems associated with carryover of soil-applied herbicides. Analytical determinations of soil residues along with bioactivity studies are required for a variety of soil types to assess carryover potential and effects of residues on commonly grown crops. Results of such research would be of great assistance to Western Canadian farmers in planning and developing crop rotations which would avoid problems associated with herbicide carryover in the soil.

# LITERATURE CITED


APPLEBY, A.P. and R.G. BRENCHLEY. 1968. Influence of paraquat on seed germination. Weed Sci. 16: 484-485.

BANTING, J.D. 1966. Studies on the persistence of Avena fatua. Can. J. Plant Sci. 46: 129-140.

BANTING, J.D. 1967. Factors affecting the activity of diallate and triallate. Weed Res. 7: 302-315.

BANTING, J.D. 1970. Effect of diallate and triallate on wild oat and wheat cells. Weed Sci. 18: 80-84.

BARDSLEY, C.E., K.E. SAVAGE and J.C. WALKER. 1968. Trifluralin behavior in soil. II. Volatilization as influenced by concentration, time, soil moisture content, and placement. Agron. J. 60: 89-92.

BARRENTINE, W.L. and G.F. WARREN. 1971a. Differential phytotoxicity of trifluralin and nitralin. Weed Sci. 19: 31-37.

BARRENTINE, W.L. and G.F. WARREN. 1971b. Shoot zone activity of trifluralin and nitralin. Weed Sci. 19: 37-41.

BAYER, D.E., C.L. FOY, T.E. MALLORY and E.G. CUTTER. 1967. Morphological and histological effects of trifluralin on root development. Amer. J. Bot. 54: 945-952.

BEESTMAN, G.R. and J.M. DEMING. 1976. Triallate mobility in soils. Weed Sci. 24: 541-544.

BETTS, M.F. and I.N. MORRISON. 1979. Fall and spring applications of trifluralin and metribuzin in fababeans (Vicia faba). Weed Sci. 27: 691-695.

BILLET, D. and R. ASHFORD. 1978. Differences in the phytotoxic response of wild oats (Avena fatua) to triallate and trifluralin. Weed Sci. 26: 273-276.

CHOW, P.N.P. 1976. Dinitroaniline herbicides for grassy weed control in rapeseed. Can. J. Plant Sci. 56: 705-713.

DARWENT, A.L. 1980. Effects of soil temperature on the phytotoxicity of trifluralin to wild oats. Can. J. Plant Sci. 60: 929-938.

DAWSON, J.H. 1963. Development of barnyardgrass seedlings and their response to EPTC. Weeds 11: 60-67.

DAWSON, J.H. and V.F. BRUNS. 1975. Longevity of barnyardgrass, green foxtail, and yellow foxtail seeds in soil. Weed Sci. 23: 437-440.

EGLEY, G.H. and R.D. WILLIAMS. 1978. Glyphosate and paraquat effects on weed seed germination and seedling emergence. Weed Sci. 26: 249-251.

FANG, S.C., P. THEISON and U.H. FREED. 1961. Effects of water evaporation, temperature, and rates of application on the retention of ethyl-N,N-di-n-propyl thiolcarbamate in various soils. Weeds 9: 569-574.

FAWCETT, R.S. and F.W. SLIFE. 1975. Germination stimulation properties of carbamate herbicides. Weed Sci. 23: 419-424.

FRIESEN, H.A., J.D. BANTING and D.R. WALKER. 1962. The effect of placement and concentration of 2,3-DCDT on the selective control of wild oats in wheat. Can. J. Plant Sci. 42: 91-104.

FRIESEN, H.A. and K.E. BOWREN. 1973. Factors affecting the control of wild oats in rapeseed with trifluralin. Can. J. Plant Sci. 53: 199-205.

GRAY, R.A. and A.J. WEIERICH. 1965. Factors affecting the vapor loss of EPTC from soils. Weed Sci. 13: 141-147.

GRAY, R.A. and A.J. WEIERICH. 1969. Importance of root, shoot, and seed exposure on the herbicide activity of EPTC. Weed Sci. 17: 223-229.

GROVER, R., J.D. BANTING and P.M. MORSE. 1979. Adsorption and bioactivity of diallate, triallate, and trifluralin. Weed Res. 19: 363-369.

HAMBLIN, E.F. 1977. The effects of soil temperature and soil moisture on the activity of triallate. Master's thesis, University of Manitoba.

HANCE, R.J., J. HOLROYD and C.E. MCKONE. 1973. Some aspects of triallate volatility. Pestic. Sci. 4: 13-17.

HARPER, L.A., A.W. WHITE, Jr., R.R. BRUCE, A.W. THOMAS and R.A. LEONARD. 1976. Soil and microclimate effects on trifluralin volatilization. J. Environ. Qual. 5: 236-242.

HARVEY, R.G. 1973. Field comparison of twelve dinitroanilines. Weed Sci. 21: 512-516.

HELLING, C.S. 1976. Dinitroaniline herbicides in soils. J. Environ. Qual. 5: 1-15.

HOLLINGSWORTH, E.B. 1980. Volatility of trifluralin from field soil. Weed Sci. 28: 224-228.

JACQUES, G.L. and R.G. HARVEY. 1979. Vapor adsorption and translocation of dinitroaniline herbicides in oats (Avena sativa) and peas (Pisum sativum). Weed Sci. 27: 371-374.

LAANIO, T.L., P.C. KEARNEY and D.D. KAUFMAN. 1973. Microbial metabolism of dinitramine. Pestic. Biochem. Physiol. 3: 271-277.

LEITIS, E. and D.G. CROSBY. 1974. Photodecomposition of trifluralin. J. Agric. Food Chem. 22: 842-848.

LIGNOWSKI, E.M. and E.G. SCOTT. 1971. Trifluralin and root growth. Plant Cell. Physiol. 12: 701-708.

MALLORY, T.E. and D.E. BAYER. 1972. The effect of trifluralin on the growth and development of cotton and safflower roots. Bot. Gaz. 133: 96-102.

MESSERSMITH, C.G., O.C. BURNSIDE and T.L. LAVY. 1971. Biological and non-biological dissipation of trifluralin from soil. Weed Sci. 19: 285-290.

MILLER, S.D. and J.D. NALEWAJA. 1975. Postemergence application of triallate for wild oat control. Weed Sci. 23: 137-141.

MILLER, S.D. and J.D. NALEWAJA. 1976. Phytotoxicity of triallate vapors to wild oats. Weed Sci. 24: 134-136.

MILLER, S.D. and J.D. NALEWAJA. 1980. Wild oat (Avena fatua) control with fall- and spring-applied triallate. Weed Sci. 28: 416-418.

MOLBERG, E.S., H.A. FRIESEN, E.V. MCCURDY and R.D. DRYDEN. 1964. Placement of diallate and triallate for control of wild oats in wheat. Can. J. Plant Sci. 44: 351-357.

MOYER, J.R. 1979. Soil organic matter, moisture, and temperature: Effect on wild oats control with trifluralin. Can. J. Plant Sci. 59: 763-768.

MULDER, C.E.G. and J.D. NALEWAJA. 1978. Temperature effect of phytotoxicity of soil-applied herbicides. Weed Sci. 26: 566-570.

PARKA, S.J. and O.F. SOPER. 1977. The physiology and mode of action of the dinitroaniline herbicides. Weed Sci. 25: 79-87.

PARKER, C. 1966. The importance of shoot entry in the action of herbicides applied to the soil. Weeds 14: 117-121.

PAROCHETTI, J.V. and G.W. DEC, Jr. 1978. Photodecomposition of eleven dinitroaniline herbicides. Weed Sci. 26: 153-156.

PAROCHETTI, J.V., G.W. DEC, Jr. and G.W. BURT. 1976. Volatility of eleven dinitroaniline herbicides. Weed Sci. 24: 529-532.

PRENDEVILLE, G.N., Y. ESHEL, M.M. SCHREIBER and G.F. WARREN. 1967. Site of uptake of soil-applied herbicides. Weed Res. 7: 316-322.

PRITCHARD, M.K. 1976. Persistence and phytotoxicity of dinitroaniline herbicides in Manitoba soils. Master's thesis, University of Manitoba.

PRITCHARD, M.K. and E.H. STOBBE. 1980. Persistence and phytotoxicity of dinitroaniline herbicides in Manitoba soils. Can. J. Plant Sci. 60: 5-11.

RAHMAN, A. 1973. Effects of temperature and soil type on the phytotoxicity of trifluralin. Weed Res. 13: 267-272.

RAHMAN, A. and R. ASHFORD. 1970. Selective action of trifluralin for control of green foxtail in wheat. Weed Sci. 18: 754-759.

RIEDER, G., K.P. BUCHOLTZ and C.A. KUST. 1970. Uptake of herbicides by soybean seed. Weed Sci. 18: 101-105.

SAVAGE, K.E. 1978. Persistence of several dinitroaniline herbicides as affected by soil moisture. Weed Sci. 26: 465-471.

SCHULTZ, D.P., H.H. FUNDERBURK, Jr. and N.S. NEGI. 1968. Effect of trifluralin on growth, morphology, and nucleic acid synthesis. Plant Physiol. 43: 265-273.

SCHWEIZER, E.E. 1979. Response of sugarbeets (Beta vulgaris) and four weed species to dinitramine. Weed Sci. 27: 28-31.

SCOTT, E.D. and R.E. PHILLIPS. 1973. Adsorption of herbicides by soybean seed. Weed Sci. 21: 71-76.

SMITH, A.E. 1969. Factors affecting the loss of triallate from soils. Weed Res. 9: 306-313.

SMITH, A.E. 1970. Degradation, adsorption, and volatility of diallate and triallate in prairie soils. Weed Res. 10: 331-339.

SMITH, A.E. 1971. Disappearance of triallate from field soils. Weed Sci. 19: 536-537.

SMITH, A.E. 1972. Persistence of trifluralin in small field plots as analyzed by a rapid gas chromatographic method. J. Agr. Food Chem. 20: 829-831.

SMITH, A.E. 1974. A multi-residue extraction procedure for the gas chromatographic determination of the herbicides dichlobenil, triallate, and trifluralin in soils. J. Chromatogr. 97: 103-106.

SMITH, A.E. 1975. Field persistence studies with herbicides in prairie soils. In Environmental Quality and Safety. Vol. 3. Edited by E. Coulston and F. Korte. Georg Thieme Publishers, Stuttgart. pp. 260-270.

SMITH, A.E. 1979. Soil persistence experiments with $^{14}C$ 2,4-D in herbicidal mixtures and field persistence studies with triallate and trifluralin both singly and combined. Weed Res. 19: 165-170.

SMITH, A.E. and B.J. HAYDEN. 1976. Field persistence studies with eight herbicides commonly used in Saskatchewan. Can. J. Plant Sci. 56: 769-771.

SPURR, A.R. 1969. A low-viscosity epoxy resin embedding medium for electron microscopy. J. Ultrastructure Research 26: 31-43.

STRUCKMEYER, B.E., L.K. BINNING and R.G. HARVEY. 1976. Effect of dinitroaniline herbicides in a soil medium on snap beans and soybean. Weed Sci. 24: 366-369.

SWANN, C.W. and R. BEHRENS. 1972. Phytotoxicity of trifluralin vapors from soil. Weed Sci. 20: 143-146.

THOMAS, A.G. 1979. Manitoba Weed Survey Questionnaire Data, 1978. Agriculture Canada.

THOMAS, A.G. 1980. Manitoba Weed Survey Questionnaire Data, 1979. Agriculture Canada.

WALKER, A. 1971. Effects of soil moisture content on the availability of soil-applied herbicides to plants. Pestic. Sci. 2: 73-76.

WEBSTER, G.R.B., C.F. SHAYKEWICH, S. KANHAI and G.J. REIMER. 1978. Availability of the herbicide trifluralin for control of wild oats as influenced by soil characteristics in four Manitoba soils. Can. J. Soil Sci. 58: 397-404.

WHITE, A.W., Jr., L.A. HARPER, R.A. LEONARD and J.W. TURNBULL. 1977. Trifluralin volatilization losses from a soybean field. J. Environ. Qual. 6: 105-110.

WRIGHT, W.L. and G.F. WARREN. 1965. Photochemical decomposition of trifluralin. Weeds 13: 329-331.

ZIMDAHL, R.L. and S.M. GWYNN. 1977. Soil degradation of three dinitroanilines. Weed Sci. 25: 247-251.

# APPENDIX

Appendix Table 1. Expert Committee on Weeds (Western Canada) Rating Scale.

| | Weed control | | | Crop tolerance |
|---|---|---|---|---|
| 9 | complete control | commercially acceptable | 9 | complete tolerance |
| 8 | excellent control | commercially acceptable | 8 | possible effect |
| 7 | good control | commercially acceptable | 7 | slight effect |
| 6 | fair control | | 6 | definite effect |
| 5 | poor control | | 5 | severe effect |
| 4 | moderate injury | | 4 | severe effect |
| 3 | definite effect | | 3 | severe effect |
| 2 | slight effect | | 2 | severe effect |
| 1 | possible effect | | 1 | severe effect |
| 0 | no effect | | 0 | complete kill |

Appendix Table 2. Mean monthly precipitation data at the Graysville, Manitoba location.

| Month | Mean Monthly Precipitation (mm) | | |
|---|---|---|---|
| | 1977-1978 | 1978-1979 | Long term average[a] |
| October | 11.2 | 10.6 | 32.0 |
| November | 27.9 | 38.7 | 26.2 |
| December | 35.8 | 41.6 | 25.4 |
| January | 11.4 | 8.5 | 24.6 |
| February | 12.7 | 32.3 | 16.3 |
| March | 7.1 | 56.8 | 33.0 |
| April | 23.4 | 92.0 | 39.1 |
| May | 125.5 | 79.5 | 54.4 |
| June | 43.4 | 68.5 | 81.8 |
| July | 101.6 | 39.2 | 71.1 |
| August | 38.8 | 44.0 | 63.2 |
| September | 95.7 | 38.6 | 51.8 |
| Year Total | 534.5 | 550.3 | 518.9 |

[a]Monthly averages for 25-29 years between 1941 and 1970.

Appendix Table 3. Trifluralin residues found in the top 5 cm of soil during the 1978 growing season.

| Applied field dosage | Plot | Trifluralin Residues[a] | | |
|---|---|---|---|---|
| | | 0 Week | 6 Weeks | 15 Weeks |
| | | ppmw[c] | | |
| Spring 0.84 kg/ha | 1 | 0.182 | 0.109 | 0.040 |
| | 2 | 0.304 | 0.115 | 0.043 |
| | 3 | 0.225 | 0.118 | 0.095 |
| | 4 | 0.211 | 0.140 | 0.091 |
| | Mean[b] | 0.230 ± 0.026 | 0.120 ± 0.007 | 0.067 ± 0.015 |
| Fall 1.12 kg/ha | 1 | 0.261 | 0.225 | 0.059 |
| | 2 | 0.345 | 0.275 | 0.152 |
| | 3 | 0.214 | 0.159 | 0.098 |
| | 4 | 0.302 | 0.232 | 0.119 |
| | Mean[b] | 0.280 ± 0.028 | 0.223 ± 0.024 | 0.109 ± 0.020 |
| Fall 2.24 kg/ha | 1 | 0.514 | 0.381 | 0.132 |
| | 2 | 0.693 | 0.584 | 0.182 |
| | 3 | 0.543 | 0.372 | 0.148 |
| | 4 | 0.652 | 0.460 | 0.159 |
| | Mean[b] | 0.600 ± 0.043 | 0.449 ± 0.049 | 0.155 ± 0.010 |

[a]Values of trifluralin residues are the average of two determinations and corrected for extraction efficiency. Extraction efficiency of trifluralin was 88%.

[b]Values following the means are standard deviation of the mean.

[c]Soil concentrations were determined on an air-dry soil weight basis.

Appendix Table 4. Trifluralin residues found in the top 5 cm of soil during the 1979 growing season.

| Applied field dosage | Plot | Trifluralin Residues[a] | | |
|---|---|---|---|---|
| | | 0 Week | 6 Weeks | 18 Weeks |
| | | ppmw[c] | | |
| Spring 0.84 kg/ha | 1 | 0.159 | 0.086 | 0.020 |
| | 2 | 0.139 | 0.050 | 0.032 |
| | 3 | 0.151 | 0.095 | 0.018 |
| | 4 | 0.111 | 0.031 | 0.003 |
| | Mean[b] | 0.140 ± 0.010 | 0.066 ± 0.015 | 0.018 ± 0.006 |
| Fall 1.12 kg/ha | 1 | 0.138 | 0.104 | 0.062 |
| | 2 | 0.314 | 0.200 | 0.084 |
| | 3 | 0.259 | 0.149 | 0.080 |
| | 4 | 0.150 | 0.120 | 0.068 |
| | Mean[b] | 0.215 ± 0.043 | 0.143 ± 0.021 | 0.074 ± 0.005 |
| Fall 2.24 kg/ha | 1 | 0.432 | 0.270 | 0.220 |
| | 2 | 0.620 | 0.352 | 0.257 |
| | 3 | 0.664 | 0.484 | 0.265 |
| | 4 | 0.450 | 0.439 | 0.236 |
| | Mean[b] | 0.542 ± 0.059 | 0.386 ± 0.047 | 0.244 ± 0.010 |

[a]Values of trifluralin residues are the average of two determinations and corrected for extraction efficiency. Extraction efficiency of trifluralin was 88%.

[b]Values following the means are standard deviation of the mean.

[c]Soil concentrations were determined on an air-dry soil weight basis.

Appendix Table 5. Dinitramine residues found in the top 5 cm of soil during the 1978 growing season.

| Applied field dosage | Plot | Dinitramine Residues[a] 0 Week | 6 Weeks | 15 Weeks |
|---|---|---|---|---|
| | | ppmw[c] | | |
| Spring 0.74 kg/ha | 1 | 0.191 | 0.045 | 0.006 |
| | 2 | 0.379 | 0.068 | 0.004 |
| | 3 | 0.314 | 0.058 | 0.006 |
| | 4 | 0.464 | 0.094 | 0.006 |
| | Mean[b] | 0.337 ± 0.058 | 0.066 ± 0.010 | 0.005 ± 0.001 |
| Fall 0.84 kg/ha | 1 | 0.448 | 0.092 | 0.021 |
| | 2 | 0.268 | 0.118 | 0.022 |
| | 3 | 0.284 | 0.115 | 0.032 |
| | 4 | 0.304 | 0.074 | 0.084 |
| | Mean[b] | 0.326 ± 0.041 | 0.100 ± 0.010 | 0.040 ± 0.015 |
| Fall 1.68 kg/ha | 1 | 0.424 | 0.169 | 0.037 |
| | 2 | 1.004 | 0.334 | 0.035 |
| | 3 | 0.486 | 0.156 | 0.047 |
| | 4 | 0.823 | 0.318 | 0.082 |
| | Mean[b] | 0.684 ± 0.138 | 0.244 ± 0.047 | 0.050 ± 0.011 |

[a]Values for dinitramine residues are the average of two determinations and corrected for extraction efficiency. Extraction efficiency of dinitramine was 97%.

[b]Values following the mean are standard deviation of the mean.

[c]Soil concentrations were determined on an air-dry soil weight basis.

Appendix Table 6. Dinitramine residues found in the top 5 cm of soil during the 1979 growing season.

| Applied field dosage | Plot | Dinitramine Residues[a] | | |
|---|---|---|---|---|
| | | 0 Week | 6 Weeks | 18 Weeks |
| | | ppmw[c] | | |
| Spring 0.74 kg/ha | 1 | 0.054 | 0.021 | 0.006 |
| | 2 | 0.101 | 0.018 | 0.009 |
| | 3 | 0.157 | 0.037 | 0.013 |
| | 4 | 0.105 | 0.031 | 0.015 |
| | Mean[b] | 0.104 ± 0.021 | 0.027 ± 0.004 | 0.011 ± 0.002 |
| Fall 0.84 kg/ha | 1 | 0.091 | 0.020 | 0.006 |
| | 2 | 0.155 | 0.025 | 0.014 |
| | 3 | 0.120 | 0.039 | 0.021 |
| | 4 | 0.170 | 0.066 | 0.012 |
| | Mean[b] | 0.134 ± 0.018 | 0.038 ± 0.010 | 0.013 ± 0.003 |
| Fall 1.68 kg/ha | 1 | 0.152 | 0.035 | 0.016 |
| | 2 | 0.830 | 0.076 | 0.014 |
| | 3 | 0.311 | 0.077 | 0.023 |
| | 4 | 0.299 | 0.059 | 0.010 |
| | Mean[b] | 0.398 ± 0.148 | 0.062 ± 0.010 | 0.016 ± 0.003 |

[a]Values for dinitramine residues are the average of two determinations and corrected for extraction efficiency. Dinitramine extraction efficiency was 97%.

[b]Values following the means are standard deviation of the mean.

[c]Soil concentrations were determined on an air-dry soil weight basis.

Appendix Table 7. Triallate residues, following application of the emulsifiable concentrate formulation, found in the top 5 cm of soil during the 1978 growing season.

| Applied field dosage | Plot | Triallate Residues[a] | | |
|---|---|---|---|---|
| | | 0 Week | 6 Weeks | 15 Weeks |
| | | ppmw[c] | | |
| Spring 1.68 kg/ha | 1 | 0.394 | 0.100 | 0.021 |
| | 2 | 0.303 | 0.218 | 0.045 |
| | 3 | 0.319 | 0.106 | 0.020 |
| | 4 | 0.761 | 0.145 | 0.081 |
| | Mean[b] | 0.444 ± 0.098 | 0.142 ± 0.027 | 0.059 ± 0.017 |
| Fall 1.68 kg/ha | 1 | 0.745 | 0.121 | 0.033 |
| | 2 | 0.782 | 0.138 | 0.072 |
| | 3 | 0.745 | 0.164 | 0.048 |
| | 4 | 0.585 | 0.154 | 0.055 |
| | Mean[b] | 0.714 ± 0.044 | 0.144 ± 0.009 | 0.052 ± 0.008 |
| Fall 3.36 kg/ha | 1 | 1.064 | 0.505 | 0.069 |
| | 2 | 2.324 | 0.542 | 0.101 |
| | 3 | 0.675 | 0.311 | 0.176 |
| | 4 | 0.681 | 0.282 | 0.145 |
| | Mean[b] | 1.186 ± 0.390 | 0.410 ± 0.066 | 0.123 ± 0.023 |

[a]Values for triallate residues are the average of two determinations and are corrected for extraction efficiency. Extraction efficiency of triallate was 94%.

[b]Values following the means are standard deviation of the mean.

[c]Soil concentrations were determined on an air-dry soil weight basis.

Appendix Table 8. Triallate residues, following application of the granular formulation, found in the top 5 cm of soil during the 1978 growing season.

| Applied field dosage | Plot | Triallate Residues[a] 0 Week | 6 Weeks | 15 Weeks |
|---|---|---|---|---|
| | | ppmw[c] | | |
| Spring 1.68 kg/ha | 1 | 0.585 | 0.191 | 0.076 |
| | 2 | 0.782 | 0.151 | 0.057 |
| | 3 | 1.197 | 0.345 | 0.128 |
| | 4 | 0.558 | 0.186 | 0.057 |
| | Mean[b] | 0.780 ± 0.148 | 0.218 ± 0.043 | 0.080 ± 0.017 |
| Fall 1.68 kg/ha | 1 | 1.170 | 0.285 | 0.064 |
| | 2 | 1.026 | 0.279 | 0.089 |
| | 3 | 0.590 | 0.247 | 0.081 |
| | 4 | 1.197 | 0.376 | 0.136 |
| | Mean[b] | 0.996 ± 0.140 | 0.298 ± 0.028 | 0.092 ± 0.015 |
| Fall 1.68 kg/ha | 1 | 3.642 | 0.542 | 0.185 |
| | 2 | 1.276 | 0.287 | 0.081 |
| | 3 | 3.915 | 0.462 | 0.352 |
| | 4 | 1.819 | 0.372 | 0.189 |
| | Mean[b] | 2.663 ± 0.656 | 0.418 ± 0.055 | 0.202 ± 0.056 |

[a]Values for triallate residues are the average of two determinations and corrected for extraction efficiency. Extraction efficiency of triallate was 94%.

[b]Values following the means are standard deviation of the mean.

[c]Soil concentrations were determined on an air-dry soil weight basis.

Appendix Table 9. Triallate residues, following application of the emulsifiable concentrate formulation, found in the top 5 cm of soil during the 1979 growing season.

| Applied field dosage | Plot | Triallate Residues[a] 0 Week | 6 Weeks | 18 Weeks |
|---|---|---|---|---|
| | | ppmw[c] | | |
| Spring 1.68 kg/ha | 1 | 0.436 | 0.142 | 0.112 |
| | 2 | 0.308 | 0.137 | 0.016 |
| | 3 | 0.455 | 0.213 | 0.037 |
| | 4 | 0.417 | 0.214 | 0.069 |
| | Mean[b] | 0.404 ± 0.033 | 0.176 ± 0.021 | 0.058 ± 0.021 |
| Fall 1.68 kg/ha | 1 | 0.320 | 0.181 | 0.031 |
| | 2 | 0.446 | 0.323 | 0.154 |
| | 3 | 0.342 | 0.252 | 0.022 |
| | 4 | 0.291 | 0.185 | 0.071 |
| | Mean[b] | 0.350 ± 0.034 | 0.235 ± 0.033 | 0.070 ± 0.030 |
| Fall 3.36 kg/ha | 1 | 0.701 | 0.660 | 0.326 |
| | 2 | 0.606 | 0.389 | 0.172 |
| | 3 | 0.426 | 0.389 | 0.156 |
| | 4 | 0.463 | 0.370 | 0.252 |
| | Mean[b] | 0.549 ± 0.064 | 0.452 ± 0.069 | 0.226 ± 0.039 |

[a]Values for triallate residues are the average of two determinations and corrected for extraction efficiency. Extraction efficiency for triallate was 94%.

[b]Values following the means are standard deviation of the mean.

[c]Soil concentrations were determined on an air-dry soil weight basis.

Appendix Table 10. Triallate residues, following application of the granular formulation, found in the top 5 cm of soil during the 1979 growing season.

| Applied field dosage | Plot | Triallate Residues[a] 0 Week | 6 Weeks | 18 Weeks |
|---|---|---|---|---|
| | | ppmw[c] | | |
| Spring 1.68 kg/ha | 1 | 0.348 | 0.328 | 0.238 |
| | 2 | 0.814 | 0.445 | 0.346 |
| | 3 | 1.266 | 0.465 | 0.282 |
| | 4 | 0.506 | 0.335 | 0.274 |
| | Mean[b] | 0.734 ± 0.202 | 0.393 ± 0.036 | 0.285 ± 0.022 |
| Fall 1.68 kg/ha | 1 | 0.409 | 0.355 | 0.299 |
| | 2 | 0.432 | 0.257 | 0.067 |
| | 3 | 0.457 | 0.261 | 0.051 |
| | 4 | 0.323 | 0.261 | 0.163 |
| | Mean[b] | 0.405 ± 0.029 | 0.284 ± 0.024 | 0.145 ± 0.057 |
| Fall 3.36 kg/ha | 1 | 0.549 | 0.506 | 0.444 |
| | 2 | 3.527 | 2.011 | 0.539 |
| | 3 | 2.533 | 2.324 | 0.840 |
| | 4 | 0.976 | 0.742 | 0.657 |
| | Mean[b] | 1.896 ± 0.691 | 1.396 ± 0.453 | 0.620 ± 0.085 |

[a]Values for triallate residues are the average of two determinations and corrected for extraction efficiency. Extraction efficiency of triallate was 94%.

[b]Values following the means are standard deviation of the mean.

[c]Soil concentrations were determined on an air-dry soil weight basis.

Appendix Table 11. Theoretical soil concentrations of trifluralin, dinitramine, and triallate at different rates of application and different depths of incorporation.

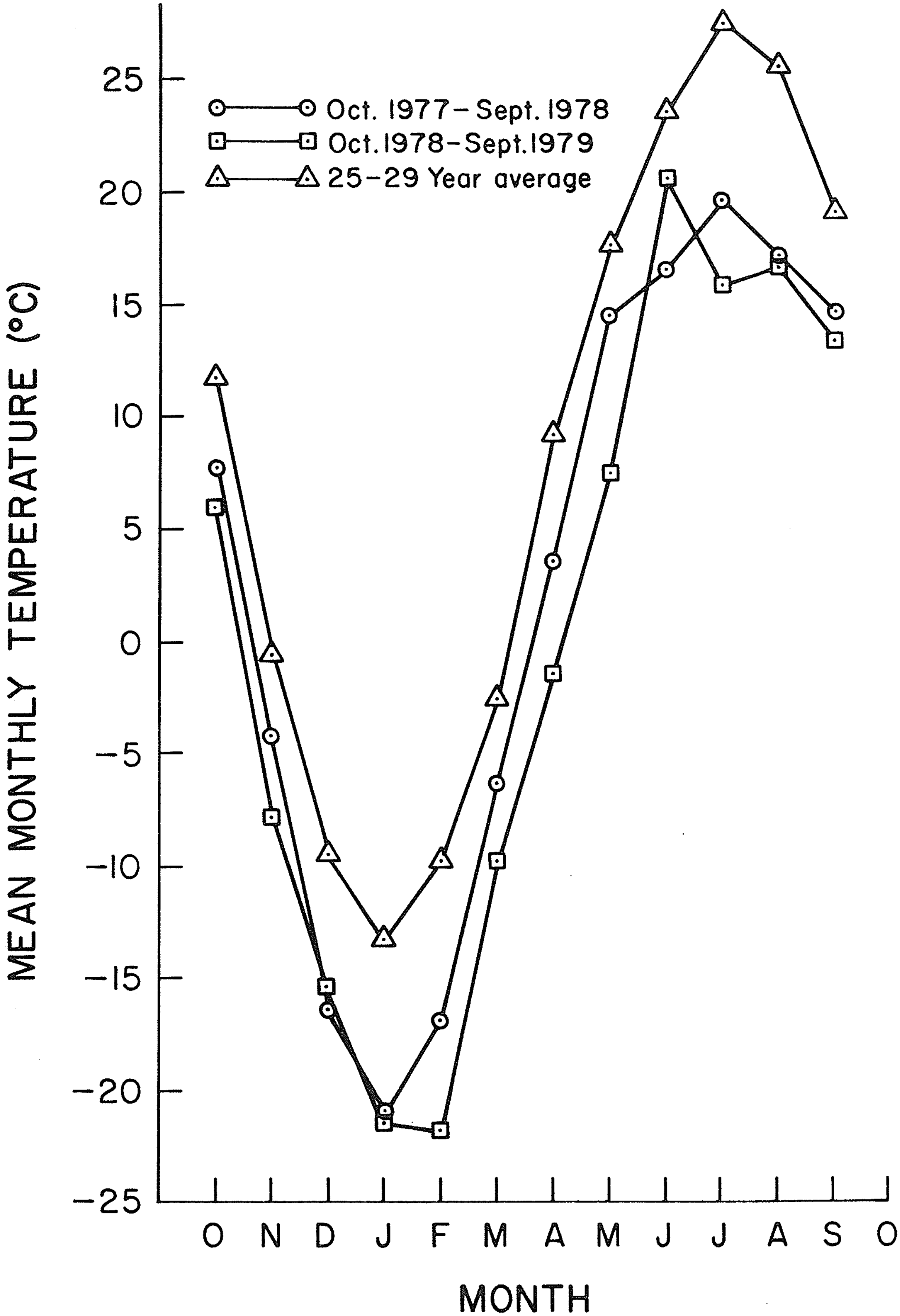
| Herbicide | Depth of incorporation[a] | Rate of application | Theoretical soil concentration[b] |
|---|---|---|---|
| | (cm) | (g/ha) | (ppmw)[c] |
| Trifluralin | 10.0 | 840 | 0.600 |
| | 10.0 | 1120 | 0.800 |
| | 10.0 | 2240 | 1.600 |
| Dinitramine | 10.0 | 740 | 0.528 |
| | 10.0 | 840 | 0.600 |
| | 10.0 | 1680 | 1.200 |
| Triallate | 7.5 | 1680 | 1.600 |
| | 7.5 | 3360 | 3.200 |

[a] Assumes herbicide is uniformly distributed throughout the cutting depth of the tandem disc.

[b] Soil concentration = $\frac{\text{Rate of application}}{\text{Soil weight}}$ where soil weight = volume X bulk density and volume = area of 1 ha (expressed as $cm^2$) X depth of incorporation in cm and bulk density = 1.4 g $cm^{-3}$.

[c] Soil concentrations were determined on an air-dry soil weight basis.

Appendix Figure 1. Mean monthly temperatures at Graysville, Manitoba from October, 1977 to September 1979.



MEAN MONTHLY TEMPERATURE (°C)
25
20
15
10
5
0
−5
−10
−15
−20
−25
Oct. 1977 − Sept. 1978
Oct. 1978 − Sept. 1979
25−29 Year average
O N D J F M A M J J A S O
MONTH