THE EFFECT OF SOIL TEMPERATURE AND SOIL MOISTURE ON THE ACTIVITY OF TRIALLATE

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Elaine Frances Hamblin

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ELAINE FRANCES HAMBLIN

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ABSTRACT

Hamblin, Elaine Frances. M.Sc., The University of Manitoba, May, 1977. The Effect of Soil Temperature and Soil Moisture on the Activity of Triallate. Major Professor: Elmer H. Stobbe.

The effectiveness of triallate [S-(2,3,3-trichloroallyl) diisopropylthiocarbamate] for the control of wild oats (*Avena fatua* L.) was evaluated under varying soil moistures and soil temperatures in the growth chamber and field. As moisture content increased from 2-5% G.M.C. in sandy loam soil, wild oat growth inhibition by triallate increased. Gravimetric moisture content of 5% and 10% gave maximum reduction in wild oat growth. At 25% GMC, or field capacity of sandy loam soil, wild oat growth inhibition by triallate was reduced. In silty clay soil, wild oat growth inhibition by triallate increased, as soil moisture increased from 5-28% GMC. Optimum triallate activity occurred at soil moistures from 28% to 53% GMC. Under field conditions, where soil moisture contents of the sandy loam soil was 5% GMC and 11% GMC for the silty clay soil at the 0-5 cm depth in the spring, triallate reduced wild oat growth significantly. At soil temperatures of 5^{0} C, triallate did not reduce wild oat growth at moisture contents from 2 to 25% GMC in sandy loam soil. At soil temperatures varying from 4^{0} C to 25^{0} C, triallate inhibited wild oat growth. Soil temperatures of 4-5^{0} C appear to be approaching the critical temperature

for the activation of triallate. Based on these results, cool soil temperatures and/or dry or field capacity (sandy loam soil) soil moisture conditions in the spring could cause a reduction in wild oat control by triallate.

INTRODUCTION

Wild oats have been recognized for many years as one of the most widespread and competitive weeds of the Canadian Prairies. Friesen (1971) reported that a hundred wild oat plants per square yard caused yield losses of 7.36 bushels in wheat and 11.57 bushels in flax.

Triallate was introduced in the 1960's as a selective herbicide for the control of wild oats in certain agronomic crops. Triallate is incorporated into the top five cms. of the soil to ensure optimum phytotoxicity to the wild oat plant. At this depth, extreme changes in the soil climate occur, which may cause triallate to be ineffective.

Relatively little is known about the effect of temperature and/or moisture extremes on the activity of triallate. A survey conducted in 1976, with pre-planting soil incorporated herbicides, indicated that of 72% of the cases studied poor weed control occurred when weather conditions were abnormal (Chow et al. 1976).

In this study, experiments were conducted under controlled environmental conditions to determine minimum and maximum soil temperatures and moisture levels for growth of wild oats and control using triallate. Field studies were conducted and soil moistures and soil temperatures were compared with the controlled environment studies.

LITERATURE REVIEW

I. Factors Affecting Triallate Performance

Triallate is a soil incorporated herbicide used in the control of wild oats. Deming et al. (1959) and Selleck (1958) suggested that one of the reasons for soil incorporation was to reduce herbicide losses due to volatilization. Holroyd (1964) emphasized the time of application and depth of incorporation as important factors in the control of wild oats and the toxicity of triallate to cereals. He reported that triallate when incorporated deeply and then seeded to wheat gave better control of wild oats but also higher toxicity to the crop than if the crop was seeded first and then the chemical applied and incorporated to a depth of 2.5-5 centimeters.

Thiocarbamate herbicides generally inhibit the growth of shoots of germinating seedlings to a greater degree than the roots. Banting (1970) found that this difference in damage was manifest by reduced numbers of mitotic divisions, increased number of abnormalities and a greater inhibition in shoot than root length. He also suggested that mitotic damage is only secondary to cell elongation or expansion.

The growth habit of a plant species can determine species sensitivity to triallate. Parker (1963) found that absorption of triallate and diallate was principally through the coleoptile and the most susceptible region is found 10 to 15 mm above the coleoptile node.

Parker found this to be true for not only wild oat but commercial varieties of wheat. However, due to the difference in the growth habit of wheat, as compared to wild oat, little damage occurs to wheat when seeded below the treated zone. In wild oat, the susceptible apical tissue is rapidly pushed upward into the treated zone by elongation of the first internode. In contrast, the apical tissue of wheat remains close to the caryopsis as the coleoptile emerges through the soil.

Banting (1967) and Yamaguchi (1961) showed that thiocarbamate herbicides are absorbed in the vapour phase by virtue of their volatility. Generally as soil temperatures increase the dissipation of volatile herbicides increase.

Gray and Weierich (1965) found that as air temperature increased from 0^{o} to $15^{o}C$, the rate of EPTC[1] vaporization from moist soil increased. Danielson and Gentner (1964) found that high soil temperatures increased the rate of dissipation of commercial EPTC from soils with high organic matter. Miller and Nalewaja (1976) reported that the degree of growth inhibition by triallate vapours of both the liquid and granular formulation increased as the temperature increased from 10^{o} to $30^{o}C$. McKercher et al. (1975) using a wild oat bioassay found that incubating triallate treated soil (concentration of triallate in the soil was 1.5 ppmw) for 20 weeks at constant temperatures of $10^{o}C$, $16^{o}C$ and $20^{o}C$ did not reduce phytotoxicity.

Penner (1971) suggested that the increase in phytotoxicity of linuron in corn and soybeans at higher temperatures can be attributed to increased herbicide uptake.

[1]Common, trade and chemical names of herbicides cited in the literature can be obtained in Appendix Table 1.

Stickler *et al*. (1969) stated that when soil moisture content of Drummer silty clay loam was increased from 80% of field capacity to field capacity, EPTC effectiveness increased but no further increase was noted at soil moisture levels above saturation. Hance *et al*. (1973) reported that as water content increased volatility of both the liquid and the granular formulation of triallate increased resulting in better wild oat control. Based on wild oat growth inhibition, Miller and Nalewaja (1976) reported an increase in vaporization of triallate as soil moisture increased for 0 to 28 ml H_2O/100 grams air dry greenhouse potting soil ((2:1:1) v/v/v Fargo clay, sand and compost). McKercher *et al*. (1975) found triallate phytotoxicity to wild oats was similar at soil moisture levels of either 5% greater than wilting point or 5% less than field capacity.

Ashton and Sheets (1959) reported that EPTC was adsorbed to a lesser extent in soil where soil moisture was near field capacity than in an air dry soil. Gray and Weierich (1965) found similar results in that EPTC loss from dry soil was much less than from moist soil. Holroyd (1964) suggested the poor wild oat control of diallate by shallow incorporation could be partially attributed to depletion of the herbicide by volatilization and/or retention and adsorption by soil particles caused by the drying out of the surface layers of the soil during a dry period.

Herbicide molecules compete with water molecules for the adsorptive sites on wet or moist soil, therefore, herbicide molecules remain in solution and are subject to loss by evaporation (Deming, 1963). Grover (1974) on the other hand stated that triallate was readily desorbed from montmorillonite clays by water. He suggested that adsorption of triallate to soil particles is due to Van der Waal's forces more so than ionic attraction. Goring and Hamaker (1972) reported that pesticides whose molecules have non-polar regions of significant size in proportion to polar regions are likely to adsorb into the hydrophobic regions (charcoal, peatmoss, cellulose) of adsorbent surfaces by means of the Van der Waal forces reinforced by hydrophobic bonding. Since triallate has a terminal alkyl group hydrophobic bonding may be an important mechanism in their adsorption to hydrophobic adsorbents.

Khan (1973) found that triallate-montmorillonite clay complexes were stable even on heating to 50^{o}C for 15 days, but when shaken with distilled water the herbicide was completely displaced from the clay. Khan suggests that the co-ordination of triallate to the exchangeable cations on the clay occur through the oxygen of the carbonyl group.

The formulation of the herbicide as either a liquid or a granule may affect the amount of moisture or temperature required for activation of the herbicide. Lovely and Staniforth (1959) stated that granule and liquid formulations of 2,4-D,CDAA, EPTC and simazine will provide similar weed control if applied under optimum environmental conditions. Jordan et al. (1968) suggested that under prolonged dry conditions, the granule formulation of CIPC (chlorpropham), EPTC, trifluralin and prometryne is more effective than the liquid formulation.

Hance et al. (1973) reported that as moisture increased from 2% to field capacity volatility of triallate was greater with the emulsifiable concentrate than the granule formulation. He found that the rate of loss of triallate from dry soil was similar for both emulsifiable concentrate and granule formulation, but from a wet soil losses were much greater from the emulsifiable concentrate.

Miller and Nalewaja (1976) found that wild oat growth inhibition by triallate vapors from soil treated with the granular formulation was less than from the liquid formulation at all temperatures (10^{o} to 30^{o}C). The effects were similar for the liquid formulation treatment at 10^{o}C and the granular formulation treatment at 30^{o}C. In a previous study, (Miller and Nalewaja, 1975), conducted in the field, the granular formulation was considerably more effective than the liquid. They suggested that the rate of volatilization of granular triallate was reduced as compared to emulsifiable concentrate and thus wild oats were exposed to lethal concentrations of the herbicide over a longer period of time.

Smith (1969) found that triallate applied at recommended field rates was not readily leached from Weyburn loam or Regina clay soil. Smith (1971) reported that the majority of the triallate was detected in the top 5 centimeters of the soil profile and only negligible residues detected at the 5 to 10 centimeter level. Koren et al. (1969) stated that lateral diffusion of thiocarbamate herbicides in the soil was more restricted than downward leaching. Ashford (1975) reported that a granule of triallate 10 millimeters from the caryopsis tip showed no significant effect on the growth of the oat seedling. Less than 10 millimeters, triallate affected either the mesocotyl, coleoptile or the first leaf of the wild oat. Moisture content of the soil was between 75-100% of field capacity. Freed et al. (1967) reported that the solubility of thiocarbamates decrease with an increase in temperature. They felt that decreased solubility could be attributed to hydrogen bonding between the thiocarbamate and water.

II. Factors Affecting Germination of Wild Oats

Early germination of wild oats before the herbicide has been activated, could be a cause for the ineffectiveness of triallate. There have been conflicting reports in regards to the optimum temperature for wild oat germination.

Mather (1946) and Leggett and Banting (1959) showed that the optimum temperature for wild oat germination was found to be between 34^oF (1.11^oC) and 50^oF (10^oC). Friesen and Shebeski (1961) and Sharma et al. (1976) showed optimum temperatures for germination was between 50^oF (10^oC) and 80^oF (26.7^oF) while poor germination occurred at 40^oF (4.44^oC). In the United Kingdom, Chancellor and Peters (1972) found that wild oat germination in the field was spread over several weeks and appeared to be initiated by a rise in soil temperature to $6\text{-}7^oC$.

Moisture level of the soil is also an important factor for germination of wild oats. Leggett and Banting (1959) showed that soil moisture content of 22% was required for germination of wild oats in medium clay loam soils and that excessive cultivation in hot weather often reduced the soil moisture content below the level required for germination. Sharma et al. (1976) reported that in clay loam soil, maximum seedling emergence occurred when soil moisture was maintained at 50 to 75% of field capacity. At field capacity, no seedlings emerged and nearly all the seeds had rotted within 11 days.

MATERIALS AND METHODS

Controlled Environment Studies

The soils used in these experiments were Almasippi sandy loam soil and Riverdale clay soil. The physical characteristics of these soils are given in Table 1.

The method of triallate application was similar for both the soil temperature and soil moisture studies. Using an atomizer, commercial grade liquid triallate, prepared in 10 milliliters of distilled water was applied to 225 grams of air dried soil and thoroughly mixed in a plastic bag. Final concentration for liquid triallate in the soil was 1.5 ppmw[1]. Commercial grade granule triallate was mixed into the soil before distilled water was added. The final concentration of granule triallate in the soil was 1.5 ppmw or 30 ppmw.

Experiment 1. Effect of soil temperature on triallate activity and wild oat germination

Soil temperature experiments were conducted using sandy loam soil in jars placed in a temperature controlled water bath. The soil moisture was kept at a constant 68% field capacity or 17.77% gravimetric moisture content (G.M.C.) for the duration of the experiment.

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[1]ppmw = parts per million by weight. Conversion of ppmw to kilograms per hectare found in Appendix Table 2.

TABLE 1. Location and physical characteristics of the soils[1]

Location	Texture	% Organic matter	Inorganic separates (%) Sand	Silt	Clay	CEC[2]
Carman	Sandy loam	4.3	75.2	3.9	20.9	18.4
Winnipeg	Silty clay	3.9	4.0	47.0	49.0	45.3

[1]Analysis by the Canada, Manitoba Soil Survey Laboratory.

[2]Cation exchange capacity in meq/100 g.

The treated soil was placed into 16 centimeter (length), 450 milliliter capacity glass jars. Into each jar, dry or imbibed (48 hours) wild oat seeds were seeded at a depth of 5 centimeters. A thermal insulator of perlite was placed on the surface of the soil to a depth of 1.5 centimeters.

The jars were placed in water glycol baths at temperatures from 4 to 30 degrees centigrade (^{o}C). The temperature in the water glycol bath was thermostatically controlled using a circulating pump and cooling coil. The jars were arranged in a completely randomized design with six replications per treatment. The experiments were conducted under laboratory conditions of air temperature and light for experiments using dry seed. Additional fluorescent lights were added when imbibed seeds were used.

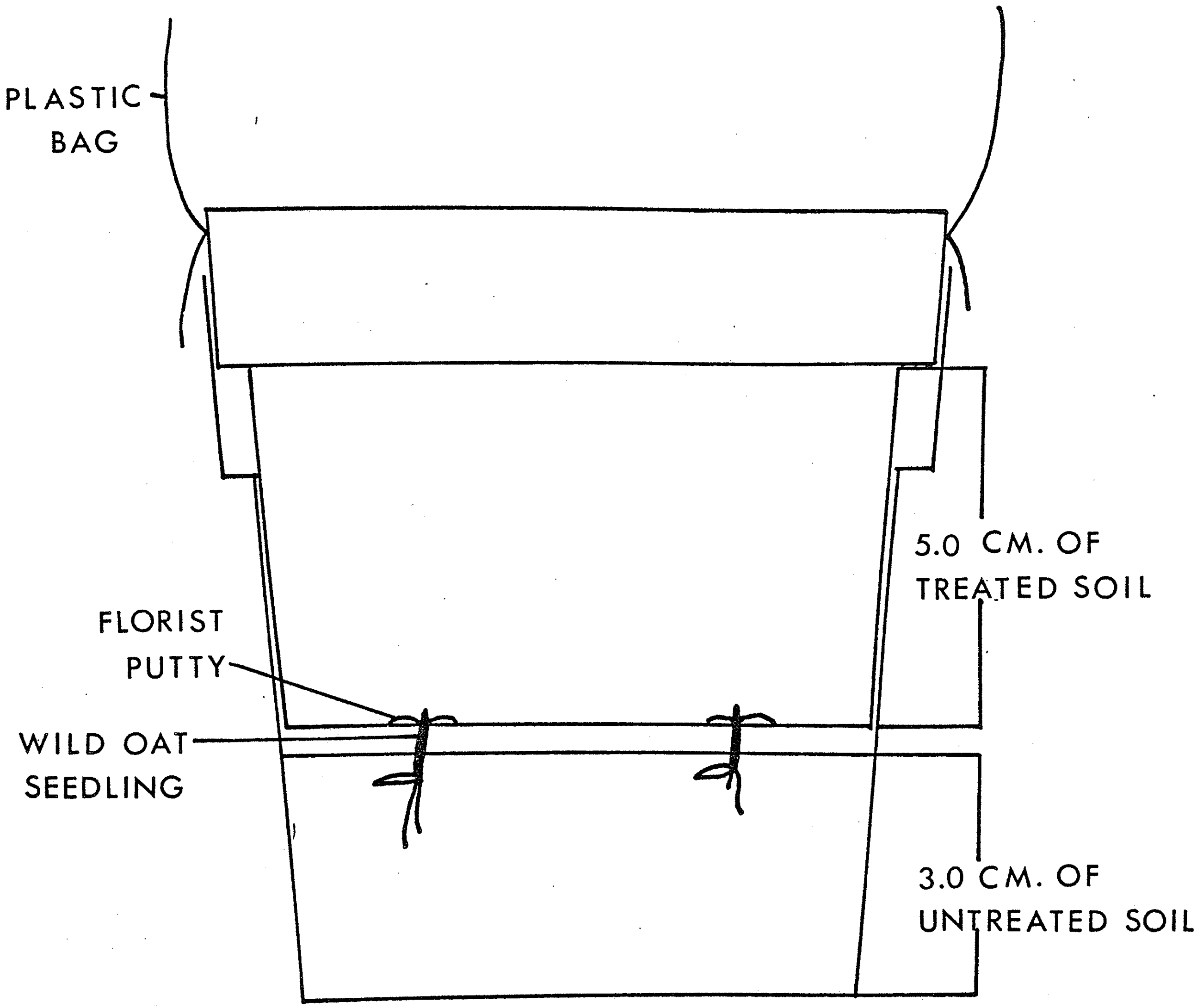
Plants were harvested after various time lengths from 15-63 days depending on the soil temperature. Shoot lengths and shoot dry weights were recorded.

Experiment 2. Effect of soil moisture on triallate activity at a constant soil temperature of $5^{o}C$

Soil moisture experiments were conducted using a two pot technique (Figure 1) in which the top pot contained the treated soil with various soil moisture contents. The bottom pot, in which the seedlings were rooting, contained moist untreated soil.

Four germinated wild oat seeds were planted in 150 grams of moistened greenhouse soil mixture in 9.4 centimeter plastic pots. The pots were placed in the dark until the coleoptile was approximately 2 centimeters above the soil surface. A smaller pot was then placed into the seeded pot, so that the coleoptile fit through the drainage

FIGURE 1. Two pot technique used in moisture studies



TOP POT - 7.5 CM.

BOTTOM POT - 9.4 CM.

hole in the top pot. Florist putty was used to seal the remaining part of the drainage holes. Triallate treated sandy loam soil at a concentration of 1.5 ppmw or 30 ppmw was then added to the top pot to a depth of 5 centimeters. A plastic bag was placed over the pot and secured to the top pot with an elastic band to minimize moisture loss. The experimental design consisted of four replications per treatment in a complete randomized design.

The experiments were carried out under 16 hours of 3730 micro watts/centimeter^2 light and 8 hours darkness. The wild oat plants were grown under high humidity conditions due to the plastic bag covering.

Plants were grown at a constant temperature of 5^{o}C and were harvested after 29 days. Both shoot length and dry weight measurements were recorded.

Experiment 3. Effect of soil moisture on triallate activity using sandy loam soil at soil temperatures of 25^{o}C day and 15^{o}C night

a) A triallate concentration of 1.5 ppmw and 30 ppmw

Experiment 3a was conducted similar to Experiment 2 except soil temperatures were maintained at 25^{o}C day and 15^{o}C night. Plants were harvested after 14 days. Both shoot length and dry weight measurements were recorded.

b) A triallate concentration of 1.5 ppmw

Experiment 3b was conducted similar to Experiment 2 except soil temperature and triallate concentrations were maintained at 25^{o}C day and 15^{o}C night and 1.5 ppmw concentration for both liquid and granule formulations. Plants were harvested after 14 days. Both shoot length and dry weight measurements were recorded.

Experiment 4. Effect of soil moisture on triallate activity using silty clay soil, at a soil temperature of 25^{o}C day and 15^{o}C night

The method used in Experiment 4 was similar to Experiment 2 except soil type, liquid triallate concentrations and soil temperature were changed to silty clay soil, 2.2 ppmw liquid triallate and 25^{o}C day and 15^{o}C night, respectively. Wild oat plants were harvested after 14 days. Both shoot lengths and shoot dry weights were obtained.

Field Studies

In the fall and spring, soil temperatures were monitored by a thermocouple recorder at depths of 2.5, 5.0 and 10.0 cm. Soil moisture contents were recorded as gravimetric moisture content measured by the oven drying method. Soil moisture contents were measured at depths of 0-5 cms and 5-10 cms.

Experiment 5. Effect of soil temperature and soil moisture on triallate activity using sandy loam soil

On the Carman location, commercial grade liquid and granule triallate were applied on October 16, 1975, November 13, 1975 and May 13, 1976 into previous rapeseed land. Plots (3 meters by 6 meters) were established in a randomized block design with four replications. Liquid triallate was applied by a bicycle sprayer with a Teejet nozzle 65015 at a pressure of 275.8 kPa and speed of 6.436 Km/h. Granule triallate was applied with a granule applicator[2]. Fall applied herbicides were incorporated using a double disc set to 7.5 cm depth (to ensure incorporation of herbicide to 5 cm depth). In the spring, plots were disced at right angles to the fall treatment. Spring applied herbicides were incorporated twice at right angles by a double disc at a 7.5 cm depth.

Wild oats emerged at Carman on May 7, 1976. Evaluations of wild oat control by triallate were made on June 1, 1976 at the 2 to 3 leaf stage. Glyphosate was applied on June 7, 1976 to control all wild oats present. Wild oats which emerged after June 13, 1976 were counted on July 5, 1976 at the early tillering stage of wild oat growth.

Experiment 6. Effect of soil temperature and soil moisture on triallate activity using silty clay soil

On the Winnipeg location, commercial grade liquid and granule triallate were applied on October 2, 1975 into previously summerfallowed land. Plots (3 meters by 6 meters) were established in a randomized block design with four replications. Prior to chemical application, wild oats were broadcast seeded and then harrowed in to give a uniform wild oat population. Commercial grade liquid triallate was applied by a bicycle sprayer with a Teejet nozzle of 6502 at a pressure of 206.5 kPa and speed of 6.436 Km/h. Granule triallate was applied with a granular applicator. Fall applied herbicides were incorporated by double discing to 7.5 cm depth with a follow up at right angles in the

[2]Spierco applicator. Manufactured by Spierco Granular Applicator, Calgary, Alberta.

spring with a diamond toothed harrow.

Wild oats emerged in the fall on October 17. 1975. Evaluation of wild oat control by triallate was made on October 28, 1975 (one leaf stage) and November 17, 1975 (one to two leaf stage). Wild oats emerged on April 15, 1976 and an evaluation was made on June 21, 1976 when the wild oats were in head.

RESULTS AND DISCUSSION

Controlled Environment Studies

Experiment 1. Effect of soil temperature on triallate activity and wild oat germination

Wild oat growth from both imbibed and dry wild oat seeds was significantly inhibited by the liquid (emulsifiable concentrate) and granule formulations of triallate at all temperatures from 4°C to 25°C (Table 2).

Cool soil temperatures appear to be retarding growth of wild oats more than affecting the activity of triallate. It took twice as long for the untreated plant to reach 9.8 cm at 4°C than it did to reach 9.3 cm at 6°C.

Dry seed germination and efficacy of triallate was also studied at 5°C and 30°C. However, after 22 days at 5°C and 15 days at 30°C, germination of the wild oat seeds had not begun.

Imbibed wild oat seeds at 4°C emerged after 25 days. An imbibition period of 48 hours at 23°C had resulted in the appearance of the radicle.

TABLE 2. Effect of soil temperature on the activity of triallate

Seed	Temp.	Days	Shoot length (cm)			Dry weight (gm)		
moisture	(^{o}C)	grown	Untreated	Liquid[1]	Granule[2]	Untreated	Liquid	Granule
Imbibed	4	63	9.8 a	0 b	0 b	0.0047 a	0 b	0 b
	6	30	9.3 a	1.0 b	0.5 b	0.0052 a	0.0011 b	0.0007 b
	8	21	10.5 a	0 b	0 b	0.0060 a	0.0003 b	0 b
	10	29	15.0 a	2.0 b	0.7 c	0.0060 a	0.0022 b	0.0010 b
Dry	10	20	13.8 a	1.33 b	0.33 b	0.0035 a	0.0007 b	0.0003 b
	15	15	16.5 a	1.83 b	0.83 b	0.0053 a	0.0018 b	0.0007 b
	20	15	16.7 a	1.00 b	0 c	0.0043 a	0.0008 b	0 c
	25	15	16.7 a	2.00 b	0.67 b	0.0055 a	0.0032 b	0.0010 c

[1]Liquid triallate concentration is 1.5 ppmw.

[2]Granule triallate concentration is 30 ppmw.

Numbers within a row followed by the same letter do not differ at the 5% level using Tukey's honestly significant difference test.

It would appear that wild oat germination does not take place at 5°C but growth of wild oats can proceed at 4°C. Even at this low temperature, 4°C, triallate controlled the growth of wild oats.

The soil temperature of 30°C was also found to be detrimental to normal germination and emergence of wild oat seeds. Sharma et al. (1976) and Friesen and Shebeski (1961) found similar results in their studies.

This study indicates that the soil temperatures at which wild oats will germinate, triallate will also be active and will control wild oats.

Experiment 2. Effect of soil moisture on triallate activity at a constant soil temperature of 5°C

At soil moisture contents from 2-25% GMC, triallate did not reduce the growth of germinated wild oat seeds at 5°C (Table 3).

This experiment was conducted in a growth chamber where both soil and air temperatures were maintained at 5°C. It would appear that the air temperature may affect the performance of triallate, since when the air temperature was not controlled as in Experiment 1, wild oat growth was reduced by triallate at 4°C. These results suggest that temperatures of 4-5°C are approaching the critical temperature for the activation of triallate.

Experiment 3. Effect of soil moisture on triallate activity using sandy loam soil at soil temperatures of 25°C day and 15°C night

a) A triallate concentration of 1.5 ppmw and 30 ppmw

Untreated plants were similar in growth at soil moisture contents

TABLE 3. Effect of varying soil moisture content on the activity of triallate at a soil temperature of 5°C

Soil moisture (% GMC)[1]	Shoot length (cm)			Dry weight (gm)		
	Untreated	Liquid[2]	Granule[3]	Untreated	Liquid	Granule
2	7.00 a	5.00 a	5.25 a	0.0047 a	0.0022 b	0.0027 b
5	4.25 a	4.25 a	4.25 a	0.0025 a	0.0023 a	0.0017 a
10	5.50 a	5.25 a	3.25 a	0.0033 a	0.0028 a	0.0015 a
25	4.50 a	8.00 b	3.00 a	0.0022 a	0.0053 b	0.0013 a

[1]% GMC = percent gravimetric moisture content.

[2]Liquid triallate concentration is 1.5 ppmw.

[3]Granule triallate concentration is 30 ppmw.

Numbers within a row followed by the same letter do not differ at the 5% level using Tukey's honestly significant difference test.

of 2-25% G.M.C.[1] (Figures 2 and 3)[2] where the roots of the wild oat plants were subjected to similar moisture content.

Shoot length measurement (Figure 2) indicated that minimum reduction in wild oat growth by triallate occurred at 2% G.M.C. (air dry soil). As the soil moisture content increased up to 5% G.M.C., the activity of triallate appeared to increase as indicated by decrease in growth of the wild oat plant. Maximum reduction in wild oat growth by liquid and granule triallate occurred at moisture contents from 5-10% G.M.C. The permanent wilting point of sandy loam soil is 7.87% G.M.C. Reduction in wild oat growth by liquid and granule triallate occurs below the permanent wilting point.

At 25% gravimetric moisture content or field capacity of the soil, triallate activity appeared to decrease as indicated by the increase in shoot length of the wild oat. At this moisture content, it was observed that the leaves of the seedling became darker green and appeared thicker than normal seedling leaves.

The dry weight of wild oat plants (Figure 3) indicates similar results as was illustrated by shoot length measurements in Figure 2. For both liquid and granule triallate, there is a general decrease in dry weight as soil moisture content increases. Except at the 25% G.M.C., dry weight per plant increases which correlates to the increase in shoot length.

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[1] Conversion of gravimetric moisture content (G.M.C.) to percent field capacity is found in Appendix Table 2.

[2] Complete data and analysis for Figures 2 and 3 are found in Appendix Table 3.

FIGURE 2. Efficacy of triallate at varying soil moisture contents as measured by shoot length where the concentration of the liquid triallate is 1.5 ppmw and granule triallate is 30 ppmw

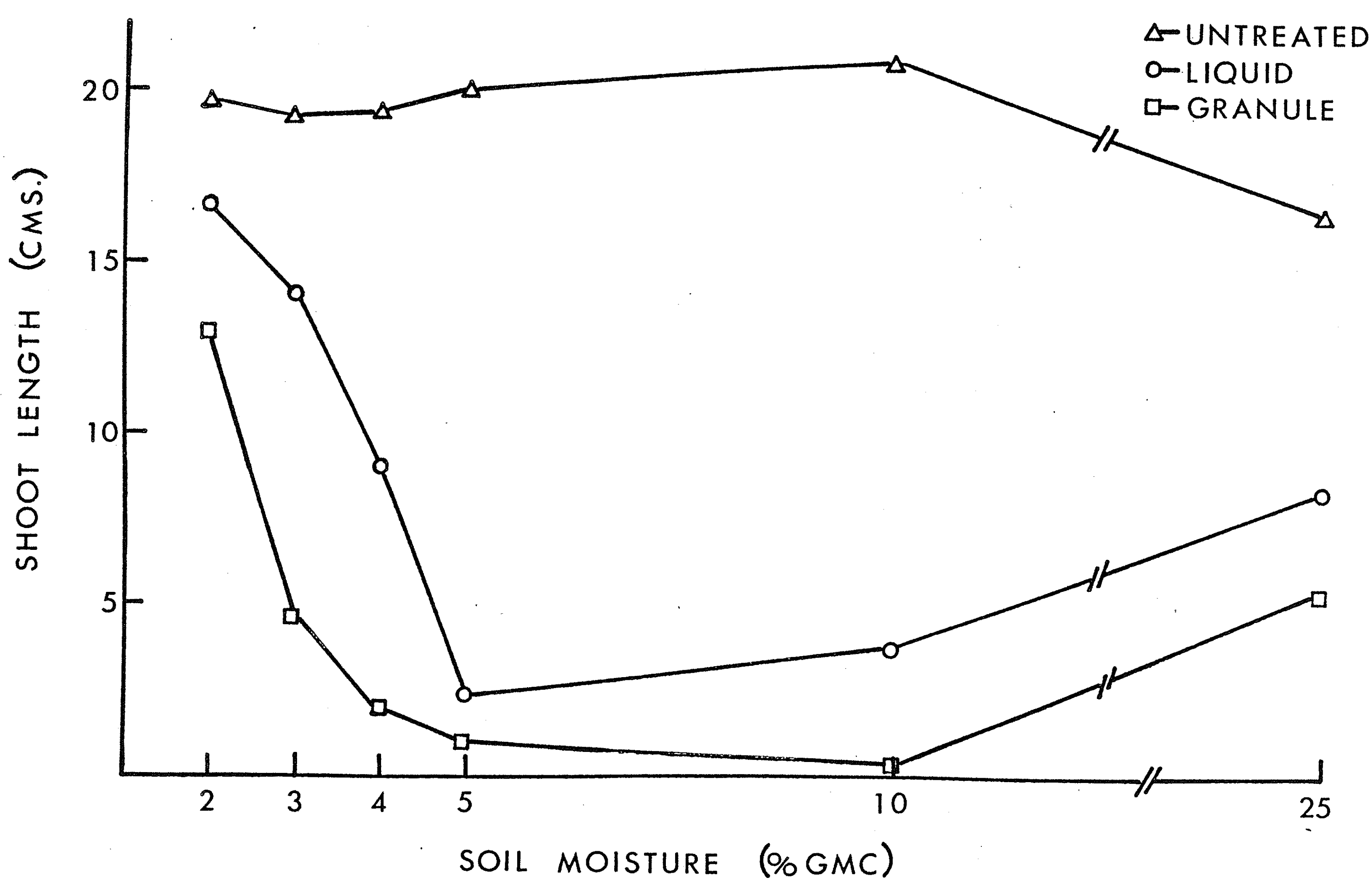
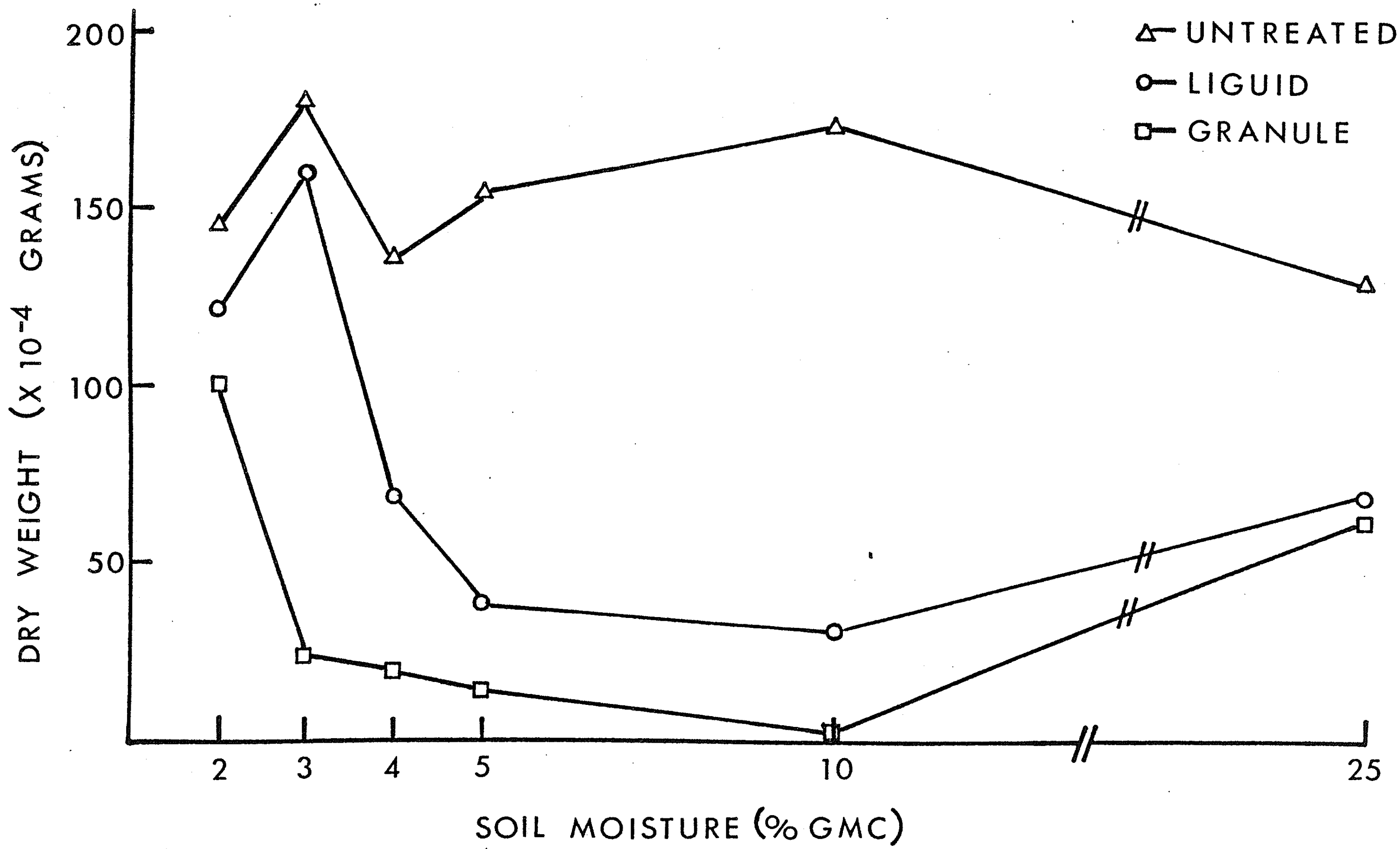

UNTREATED
LIQUID
GRANULE
SHOOT LENGTH (CMS.)
20
15
10
5
2
3
4
5
10
25
SOIL MOISTURE (% GMC)

FIGURE 3. Efficacy of triallate at varying soil moisture contents as measured by shoot dry weight where the concentration of liquid triallate is 1.5 ppmw and granule triallate is 30 ppmw


UNTREATED
LIGUID
GRANULE
DRY WEIGHT (X 10^-4 GRAMS)
200
150
100
50
2
3
4
5
10
25
SOIL MOISTURE (% GMC)

b) A triallate concentration of 1.5 ppmw

Performance of liquid triallate at 1.5 ppmw was similar to the activity found in Experiment 3a. However, wild oat growth inhibition by triallate was reduced as granule triallate concentration decreased from 30 ppmw to 1.5 ppmw (Figures 4 and 5)[3].

Liquid and granule triallate followed a similar trend of increasing activity as moisture increased up to the 4% G.M.C. However, at the 5 and 10% G.M.C, wild oat growth inhibition by liquid triallate was superior to granule triallate. The decrease in control by granule triallate under controlled environmental conditions when compared to the liquid was also reported by Miller and Nalewaja (1976).

At the high moisture content of 25% G.M.C. or field capacity, the activity of granule triallate did not decrease but was similar to the activity that was found at 5 and 10% G.M.C. when comparing the granule triallate treatment with the untreated plants.

Experiment 4. Effect of soil moisture on triallate activity using silty clay soil, at a soil temperature of 25°C day and 15°C night

Untreated wild oat plants were similar in growth at soil moisture contents of 5-71% G.M.C. (Figures 6 and 7)[4].

At moisture contents of 5-23% G.M.C., triallate did not cause a significant reduction in wild oat growth. As the soil moisture content

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[3] Complete data and analysis for Figures 4 and 5 are found in Appendix Table 4.

[4] Complete data and analysis for Figures 6 and 7 are found in Appendix Table 5.

FIGURE 4. Efficacy of triallate (1.5 ppmw) at varying soil moisture contents as measured by shoot length

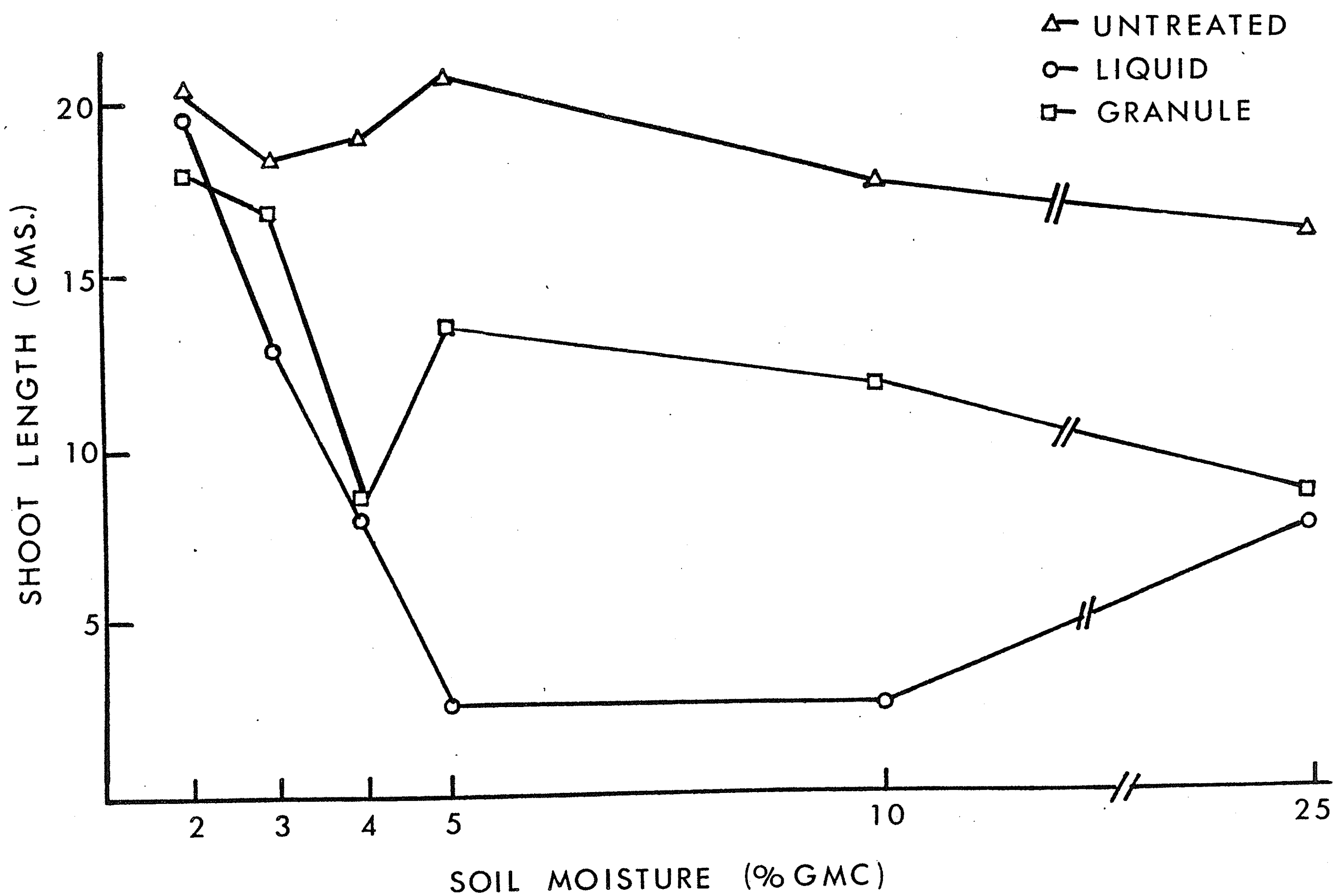

UNTREATED
LIQUID
GRANULE
SHOOT LENGTH (CMS.)
20
15
10
5
2
3
4
5
10
25
SOIL MOISTURE (% GMC)

FIGURE 5. Efficacy of triallate (1.5 ppmw) at varying soil moisture contents as measured by shoot dry weight

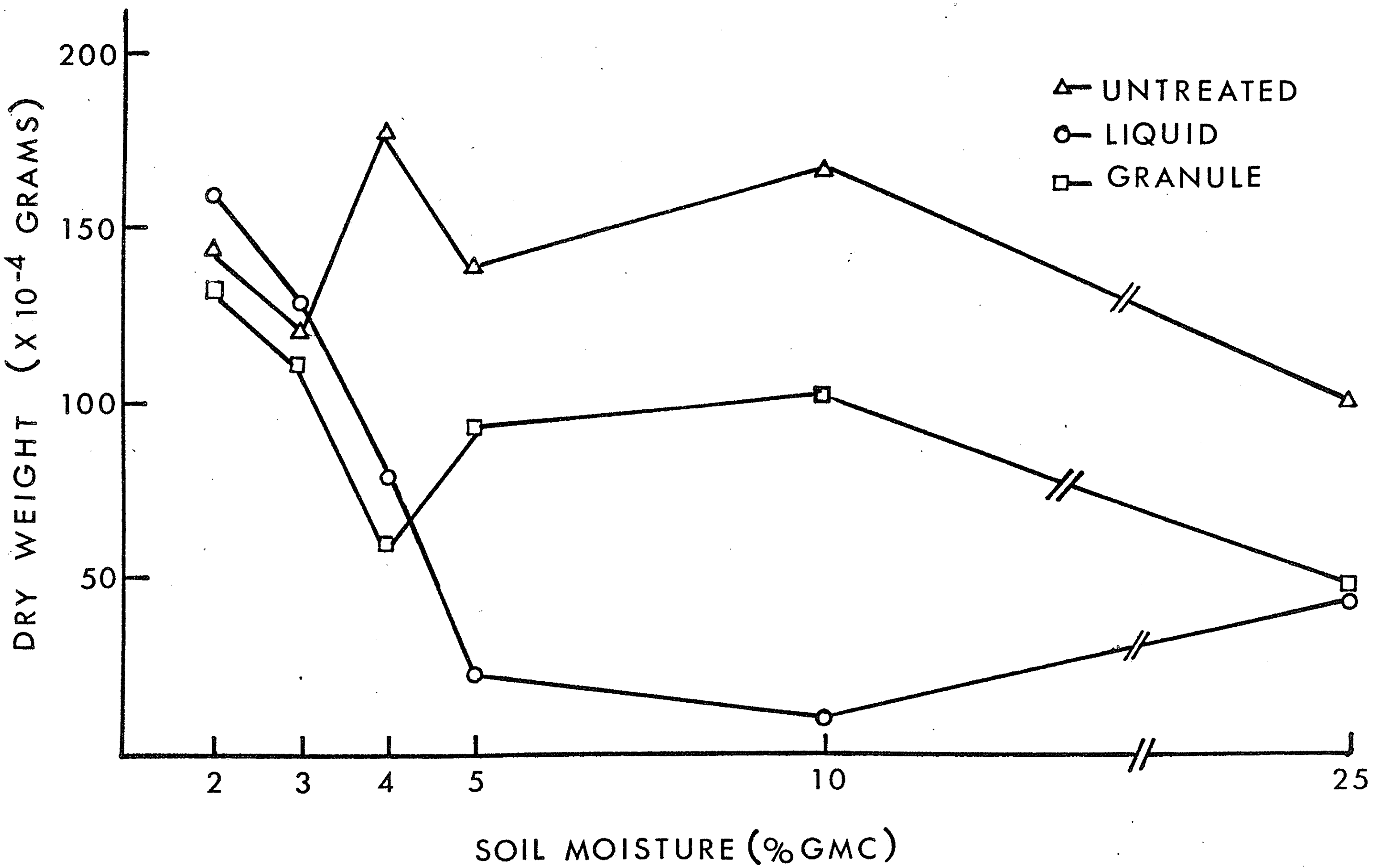

UNTREATED
LIQUID
GRANULE
DRY WEIGHT (X 10^-4 GRAMS)
200
150
100
50
2
3
4
5
10
25
SOIL MOISTURE (% GMC)

FIGURE 6. Efficacy of liquid triallate (2.2 ppmw) at varying soil moisture contents as measured by shoot length using silty clay soil

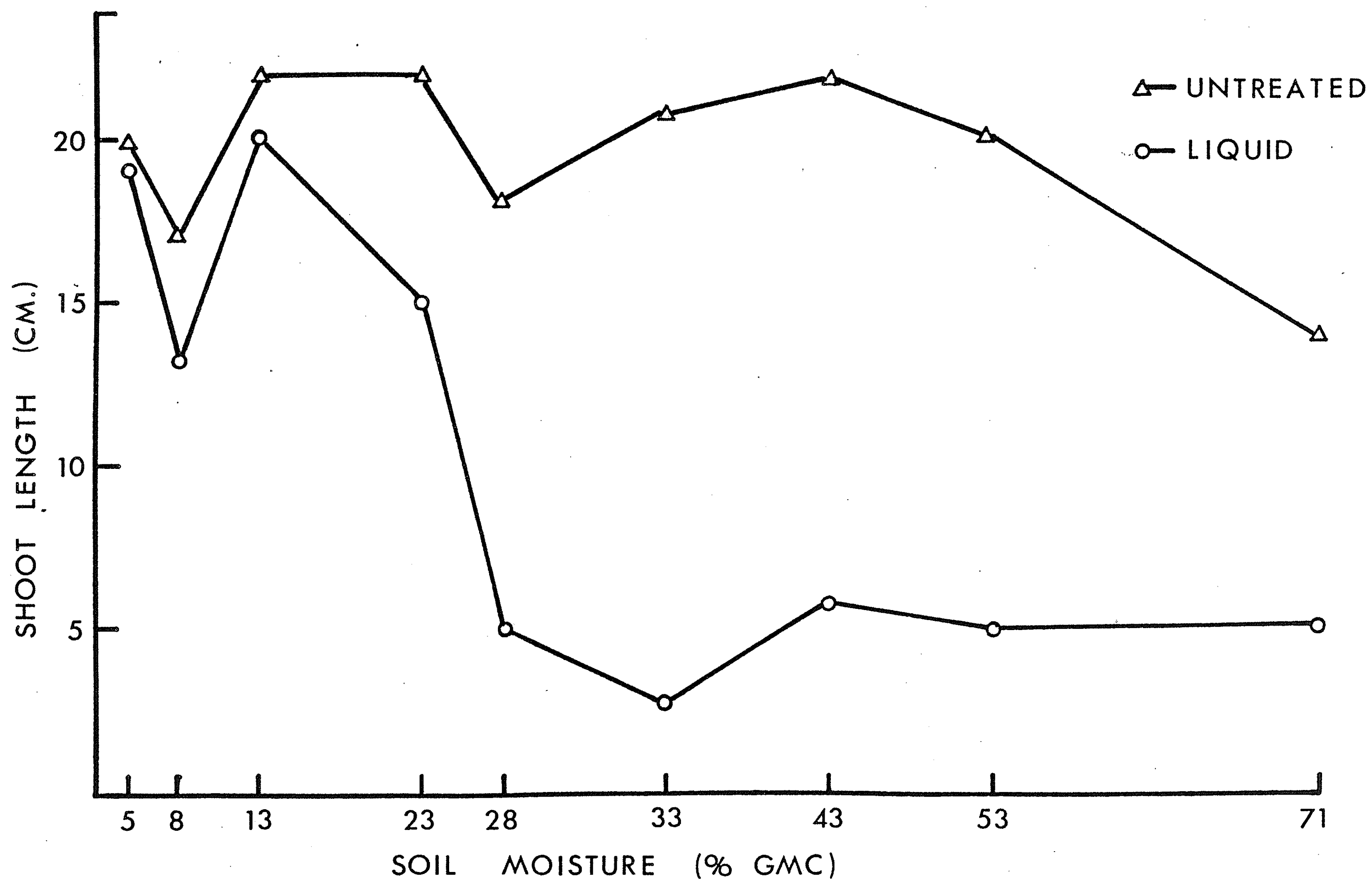
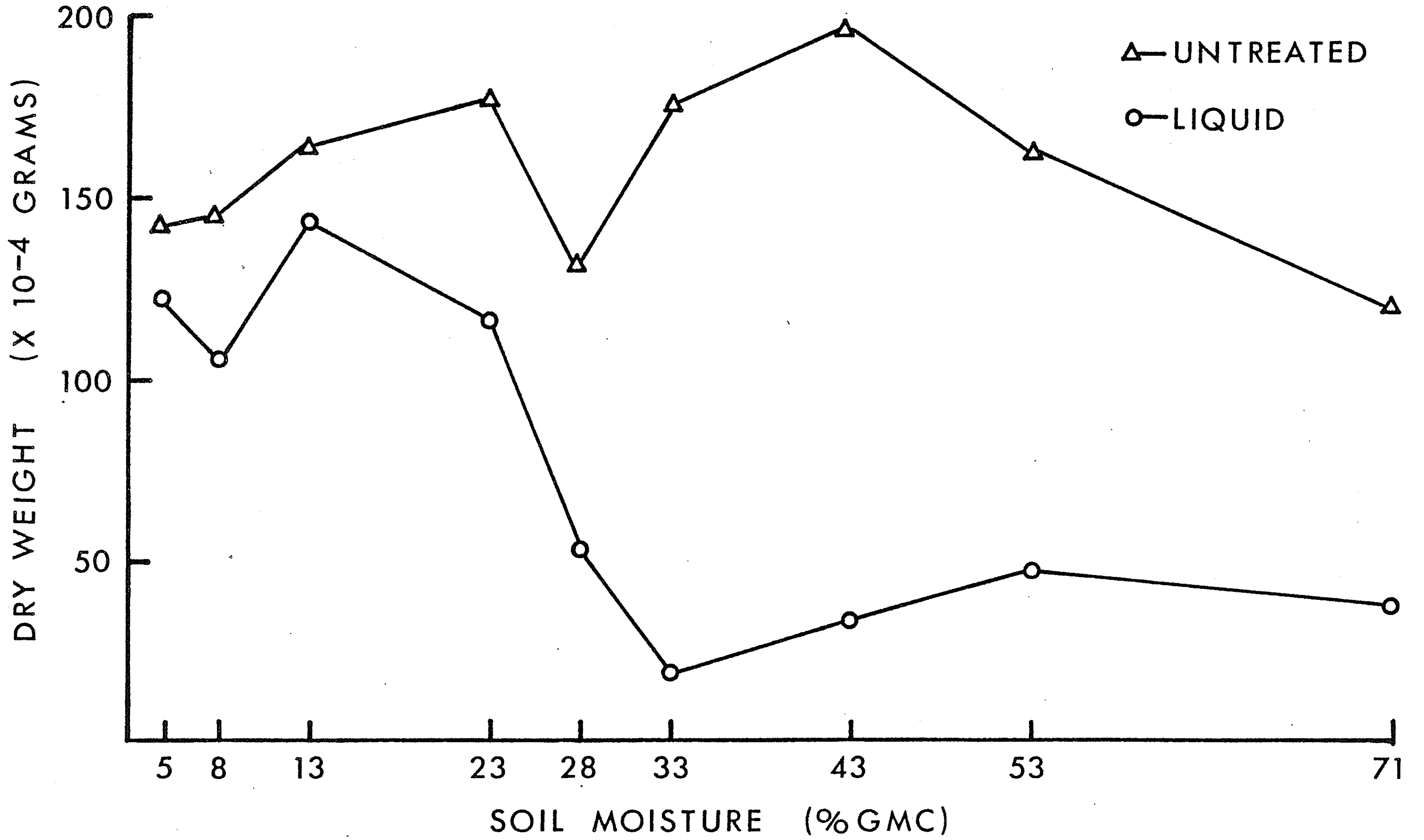

UNTREATED
LIQUID
SHOOT LENGTH (CM.)
20
15
10
5
5
8
13
23
28
33
43
53
71
SOIL MOISTURE (% GMC)

FIGURE 7. Efficacy of liquid triallate (2.2 ppmw) at varying soil moisture contents as measured by shoot dry weight using silty clay soil


UNTREATED
LIQUID
DRY WEIGHT (X 10-4 GRAMS)
200
150
100
50
5
8
13
23
28
33
43
53
71
SOIL MOISTURE (% GMC)

in the soil increased up to 28% G.M.C., the activity of triallate appeared to increase as indicated by the decrease in growth of the wild oat plant. Significant reduction in wild oat growth occurred at soil moisture contents from 28-71% G.M.C.

At soil moisture content of 39.84% or field capacity of silty clay soil, extrapolation of Figure 6 and 7 indicates that liquid triallate will significantly decrease wild oat growth.

Both shoot length (Figure 6) and shoot dry weight (Figure 7) of the wild oat plants indicated similar results.

Field Studies

Experiment 5. Effect of soil temperature and soil moisture on triallate activity using sandy loam soil

Triallate formulations were applied October 16, 1975 and November 13, 1975 to determine if triallate would be lost from the soil due to the rise in soil temperature[5] (approximately 16^{o}C) in early November. From the results of the evaluation, no herbicide loss appeared to have occurred due to the rise in temperature to affect triallate control of wild oats (Table 4).

The low moisture content during May 1976 of approximately 4% gravimetric moisture content at the 0-5 cm depth, did not appear to affect herbicidal activity. From the data (Table 4), there appears

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[5] Soil moisture and soil temperature data and air temperature and precipitation data for Carman (sandy loam soil) are given in Appendix Tables 6 and 7, respectively.

TABLE 4. Effect of liquid and granule triallate formulations on wild oat densities in sandy loam soil

Application date	Triallate treatment	Rate (A.I.)[1] kg/ha	Wild oats/ square meter June 1, 1976[2]	July 5, 1976
October 16, 1975	Emulsifiable concentrate[3]	0.000	61.75 a	32.50 a
		0.560	38.50 b	9.00 b
		1.120	14.00 c	8.50 b
		1.400	15.00 c	7.00 b
		1.680	9.00 c	3.00 b
		2.240	3.75 c	3.00 b
	Granule[4]	0.000	27.00 a	16.00 a
		0.560	8.75 b	5.50 b
		1.120	8.25 b	4.50 b
		1.400	5.00 b	2.00 b
		1.680	2.25 b	1.50 b
		2.240	1.75 b	1.50 b
November 13, 1975	Emulsifiable concentrate	0.000	78.50 a	26.50 a
		0.560	24.75 b	12.00 b
		1.120	17.25 b	14.50 b
		1.400	15.00 b	4.50 b
		1.680	6.50 b	4.50 b
		2.240	5.75 b	4.50 b
	Granule	0.000	64.75 a	29.50 a
		0.560	15.00 b	21.00 b
		1.120	9.00 b	9.00 b
		1.400	9.50 b	6.50 b
		1.680	6.75 b	5.00 b
		2.240	3.75 b	3.00 b
May 13, 1976	Emulsifiable concentrate	0.000	70.25 a	53.50 a
		0.560	20.50 b	14.00 b
		1.120	20.00 b	19.00 b
		1.400	15.00 b	7.00 b
		1.680	7.50 b	5.00 b
		2.240	9.50 b	1.50 b
	Granule	0.000	18.50 a	12.00 a
		0.560	5.25 b	0.00 b
		1.120	3.25 b	4.00 b
		1.400	2.50 b	0.50 b
		1.680	2.25 b	0.50 b
		2.240	1.50 b	0.00 b

[1]A.I. = Active Ingredient

[2]Evaluation date of wild oat control by triallate

[3]Triallate emulsifiable concentrate formulation is 4 lb/gal (339 g/l) active ingredient.

[4]Triallate granule formulation is 10% active ingredient.

Numbers within a treatment column followed by the same letter do not differ at the 5% level using Tukey's honestly significant difference test.

to be a significant difference between the untreated and the following rates of triallate (0.560-2.24 kg/ha).

The total wild oat population, after the glyphosate application on June 7, was considerably reduced but there was still evidence of differences in activity of triallate between the rates. The soil temperatures at this time averaged around 24°C. Soil moisture increased in early June, thus supplying sufficient moisture for wild oat germination and control by triallate.

In all cases, there was a general trend towards increase in activity as rate of triallate increased. There also appears to be a slight increase in control by the granule formulation as compared to the liquid formulation although not significant.

Experiment 6. Effect of soil temperature and soil moisture on triallate activity using silty clay soil

Liquid and granule triallate significantly reduced wild oat growth on Winnipeg clay soil in the fall of 1975 and spring of 1976 (Table 5).

An evaluation of wild oat growth was conducted on October 28, 1975 and November 17, 1975 due to an emergence of wild oats on October 17, 1975. At both dates, triallate reduced wild oat growth significantly as compared to the untreated plots. Soil moisture[6] conditions averaged

[6] Soil moisture and soil temperature data and air temperature and precipitation data for Winnipeg (silty clay soil) are given in Appendix Tables 8 and 9, respectively.

TABLE 5. Effect of liquid and granule triallate formulations on wild oat densities on silty clay soil

Triallate treatment	Rate (A.I.)[1] kg/ha	Wild oats/0.5 sq. meter Oct. 28, 1975[2]	Wild oats/0.5 sq. meter Nov. 17, 1975	Wild oats/12 sq. meter June 21, 1975
Emulsifiable concentrate[3]	0.000	62.00 a	120.75 a	124.00 a
	0.560	5.00 b	16.75 b	47.25 b
	1.120	5.50 b	18.75 b	20.75 c
	1.400	4.25 b	9.00 b	15.25 c
	1.680	4.50 b	11.50 b	11.75 c
	2.240	1.50 b	5.00 b	6.50 c
Granule[4]	0.000	39.25 a	113.75 a	106.25 a
	0.560	7.50 b	15.00 b	26.00 b
	1.120	7.25 b	19.25 b	17.75 b
	1.400	7.75 b	11.50 b	14.75 b
	1.680	2.25 b	16.00 b	14.50 b
	2.240	2.25 b	11.75 b	7.75 b

[1]A.I. = Active Ingredient

[2]Evaluation date of wild oat control by triallate

[3]Triallate emulsifiable concentrate formulation is 4 lb/gal (399 g/l) active ingredient.

[4]Triallate granule formulation is 10% active ingredient

Numbers within a treatment column followed by the same letter do not differ at the 5% level using Tukey's honestly significant difference test.

around 25% GMC throughout the fall. However, soil temperatures were decreased from $4^{o}C$-$3^{o}C$ prior to October 28, 1975 to just above $0^{o}C$ by November 1975.

In the spring of 1976, evaluation of wild oat growth was made on June 21, 1975 when the wild oats were in head. Results from the evaluation, indicated a wild oat growth reduction in all triallate treatments when compared to the untreated plots. Prior to emergence of wild oats on April 15, 1976, soil temperatures were below $15^{o}C$. Soil moisture was adequate for wild oat growth and control at 23% GMC, at the 0-5 cm depth and 41% GMC at the 5-10 cm depth. Low soil moisture content of 11%GMC at the 0-5 cm depth in May did not appear to affect herbicidal activity. However, rain at the beginning of June brought soil moisture up to an average of 40% GMC.

Generally at all evaluation dates, there appears to be a trend towards an increase in control of wild oats by triallate as concentration of the triallate formulations increase.

In the fall, the liquid triallate appeared to control slightly better than the granule although not significantly. This may be due to the rate of volatilization of the granule herbicide is reduced as compared to the liquid triallate as suggested by Miller and Nalewaja (1975).

In the spring, there appears to be no significant difference between liquid and granule triallate in their control of wild oats.

SUMMARY AND CONCLUSIONS

Soil temperature could be a factor causing inadequate control of wild oats by triallate in the spring, however, the overriding factor appears to be soil moisture.

Results suggest that the critical soil temperature for the activation of triallate is from 4-5^{o}C. However, results also indicate that wild oats will not germinate at 4-5^{o}C but will at 6-7^{o}C (Chancellor and Peters, 1972) or 10^{o}C (Experiment 1 and Friesen and Shebeski, 1961). It therefore appears that at soil temperatures at which wild oats will germinate, triallate will also be active and will reduce wild oat growth.

From the experiments conducted, at varying soil moistures, triallate will inhibit wild oat growth under normal moisture conditions. Only at extreme soil moisture contents of air dry soil (sandy loam and silty clay soil) and at a high moisture content of field capacity (sandy loam soil) is triallate activity and thus reduction in wild oat growth decreased.

The inadequate control of wild oats by triallate under dry soil conditions could be attributed to a similar reason as suggested by Holroyd (1964) with diallate. He suggested that poor wild oat control by diallate when shallow incorporated could be partially attributed to depletion of the herbicide by volatilization and/or retention and adsorption by soil particles in a dry period. Triallate under low moisture contents could also be retained and adsorbed by the soil particles and thus made unavailable for control. However, as moisture content increases from 2 to 5% gravimetric moisture content (sandy loam soil) and 5 to 28% G.M.C. (silty clay soil) activity of triallate is increasing due to water molecules replacing the herbicide molecules on the soil particle (Khan, 1973).

It is interesting to note that even under abnormally high granular concentrations of 30 ppmw, granule triallate will not give maximum reduction at low soil moistures of 2 to 3% G.M.C. in Almasippi sandy loam soil.

Under field conditions, where soil moisture contents of the sandy loam soil was 5% G.M.C. and 11% G.M.C. for the silty clay soil at the 0-5 cm depth in the spring, triallate reduced wild oat growth significantly.

Soil temperatures in the field appeared adequate for wild oat germination and control by triallate. The rise in soil temperature in the fall to 16^{o}C at the Carman location (sandy loam soil) did not reduce the efficacy of triallate.

In comparing the efficacy of liquid and granule triallate in the fall at Winnipeg, liquid triallate appeared to control slightly better than the granule triallate, although it was not significant. In the spring, there appeared to be no difference in control. The suggested reason is that the rate of volatilization of granule herbicide is reduced as compared to the liquid triallate (Miller and Nalewaja, 1975).

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APPENDICES

TABLE 1. Common, trade and chemical name of herbicides cited in literature review

Common name	Trade name	Chemical name	Reference
CDAA	Randox	N,N-diallyl-2-chloroacetamide	Lovely and Staniforth, 1959
Chlorpropham (CIPC)	Furloe, Sprout nip Chloro IPC	isopropyl *M*-chlorocarbanilate	Jordan et al., 1968
Diallate	Avadex	S-(2,3-dichloroallyl) diisopropyl-thiocarbamate	Holyroyd, 1964
2,4-D	2,4-D	(2,4-dichlorophenoxy)acetic acid	Lovely and Staniforth, 1959
EPTC	Eptam	S-ethyl dipropylthiocarbamate	Ashton and Sheets, 1959 Danielson and Gentner, 1964 Gray and Weierich, 1965 Stickler et al., 1969
Linuron	Lorox	3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea	Penner, 1971
Prometryne	Gesagard Primatol	2,4-bis-(isopropylamino)-6-(methylthio)-S-triazine	Jordan et al., 1968
Triallate	Avadex BW	S-(2,3,3-trichloroallyl)diisopropyl-thiocarbamate	Ashford, 1975 Deming et al., 1959 Grover, 1974 Hance et al., 1973 Holroyd, 1964 Khan, 1973 McKercher et al., 1975 Miller and Nalewaja, 1975 & 1976 Parker, 1963 Selleck, 1958 Smith, 1969
Trifluralin	Treflan	*a,a,a*,-trifluoro-2,6-dinitro-N,N-dipropyl-*p*-toluidine	Jordan et al., 1968

TABLE 2. Conversion of ppmw to kilograms per hectare and gravimetric soil moisture content (G.M.C.) to percent field capacity

P.P.M.W.	to	Kilograms/hectare
1.5		1.121
2.2		1.644
30		22.419

Gravimetric moisture content	to	Percent field capacity
	Sandy loam soil	
2%		8% (air dry soil)
3%		12%
4%		16%
5%		20%
10%		40%
25%		100%
	Silty clay soil	
5%		13% (air dry soil)
8%		20%
13%		33%
23%		58%
28%		70%
33%		83%
43%		108%
53%		133%
71%		178%

TABLE 3. Effect of soil moisture on liquid triallate (1.5 ppmw) and granule triallate (30 ppmw) activity in sandy loam soil

Soil moisture	Shoot length (cm)			Dry weight (gm)		
(% GMC)[1]	Untreated	Liquid[2]	Granule[3]	Untreated	Liquid	Granule
2	19.75 a	16.50 a	13.50 a	0.0148 a	0.0122 a	0.0102 a
3	19.00 a	14.25 b	4.50 c	0.0181 a	0.0159 a	0.0032 b
4	19.25 a	9.00 b	2.00 c	0.0141 a	0.0068 b	0.0030 b
5	20.00 a	2.50 b	1.00 b	0.0155 a	0.0040 b	0.0012 b
10	21.00 a	3.50 b	0.00 b	0.0177 a	0.0035 b	0.0000 b
25	16.50 a	8.25 b	5.25 c	0.0139 a	0.0068 b	0.0056 b

[1]%GMC = percent Gravimetric Moisture Content
[2]Liquid triallate concentration is 1.5 ppmw
[3]Granule triallate concentration is 30 ppmw
Numbers within a row followed by the same letter do not differ at the 5% level using Tukey's honestly signficantly difference test.

TABLE 4. Effect of soil moisture on liquid and granule triallate (1.5 ppmw) activity

Soil moisture	Shoot length (cm)			Dry weight (gm)		
(% GMC)[2]	Untreated	Liquid[1]	Granule[1]	Untreated	Liquid	Granule
2	20.25 a	19.25 a	17.50 a	0.0146 a	0.0160 a	0.0135 a
3	18.00 a	13.00 b	16.75 a	0.0126 a	0.0129 a	0.0113 a
4	18.75 a	8.00 b	8.50 b	0.0118 a	0.0075 a	0.0057 a
5	20.50 a	2.75 c	13.50 b	0.0143 a	0.0053 b	0.0097 a
10	17.50 a	2.75 b	12.50 a	0.0168 a	0.0045 a	0.0103 a
25	16.50 a	8.00 b	8.25 b	0.0103 a	0.0043 b	0.0045 b

[1]Liquid and granule triallate concentration is 1.5 ppmw.

[2]%GMC = percent Gravimetric Moisture Content.

Numbers within a row followed by the same letter do not differ at the 5% level using Tukey's honestly significant difference test.

TABLE 5. Effect of soil moisture on triallate activity using silty clay soil

Soil moisture	Shoot length (cm		Dry weight (gm)	
(% GMC)[1]	Untreated	Liquid[2]	Untreated	Liquid
5	20.00 a	19.25 a	0.0142 a	0.0125 a
8	17.25 a	13.00 a	0.0145 a	0.0106 a
13	22.00 a	19.50 a	0.0175 a	0.0148 a
23	22.00 a	14.50 a	0.0177 a	0.0117 a
28	17.50 a	5.25 b	0.0130 a	0.0053 b
33	20.50 a	3.00 b	0.0176 a	0.0023 b
43	22.00 a	5.50 b	0.0199 a	0.0039 b
53	19.75 a	5.00 b	0.0162 a	0.0047 b
71	13.75 a	5.00 b	0.0124 a	0.0039 a

[1]%GMC = percent Gravimetric Moisture Content.

[2]Liquid triallate concentration is 2.2 ppmw.

Numbers within a row followed by the same letter do not differ at the5% level using Tukey's honestly significant difference test.

TABLE 6. Soil temperature and moisture data recorded at Carman

	Soil temperature							
	Maximum (°C)			Minimum (°C)			Soil moisture (GMC)	
Date	2.5 cm	5.0 cm	10.0 cm	2.5 cm	5.0 cm	10.0 cm	0-5 cm	5-10 cm
Oct. 23, 1975	2.0	4.0	6.0					
24	5.0	7.0	7.0	0	2.0	5.0	13.0	16.0
25	8.0	8.0	5.0	0	4.0	4.0	15.8	19.4
26	5.0	6.0	6.0	5.0	6.0	4.0		
27	3.0	4.0	5.0	3.0	4.0	4.0		
28	4.0	5.0	5.0	0	3.0	3.0		
29	3.4	6.0	6.0	3.2	5.0	5.0		
30	10.0	10.0	7.0	4.0	5.0	5.0	9.2	15.0
31	5.0	6.0	6.0	3.0	5.0	6.0		
Mean	5.04	6.22	5.89	2.28	4.25	4.50	11.67	16.8
Nov. 1, 1975	11.0	10.0	6.0	0	4.0	5.0		
2	10.0	10.0	7.0	5.0	7.0	6.0		
3	12.8	12.0	8.5	7.0	8.0	7.0	7.8	20.0
4	17.0	16.0	11.0	8.5	9.0	8.0		
5	16.0	16.0	11.0	3.0	6.0	7.0		
6	13.0	12.5	9.4	6.0	8.0	9.0	6.2	13.5
7	9.0	11.0	9.4	9.0	9.0	9.0		
8	6.0	9.0	8.5	4.0	6.0	7.0		
9	1.3	4.5	6.0	1.0	3.0	4.0		
10	4.0	5.0	6.0	1.5	4.0	5.0	8.0	14.8
11	1.3	3.0	3.5	0	2.0	3.0		
12	0	3.0	3.0	- 2.0	2.0	3.0		
13	0	1.0	2.0	- 2.0	0	1.0	7.9	8.7
14	4.5	3.0	4.0	- 2.0	0	0		
15	10.0	9.0	6.0	2.0	3.0	3.0		
16	9.0	7.0	6.0	5.0	6.0	5.0		
17	6.0	6.5	6.0	5.0	6.0	6.0		
18	5.0	6.0	6.0	4.0	5.0	5.0		
19	2.0	4.0	4.0	1.0	3.0	4.0		
20	0	2.0	3.0	- 1.0	1.0	3.0	13.4	14.8
21	- 2.0	1.0	2.0	- 3.0	1.0	1.0		
22	- 2.5	- 1.0	0	- 2.5	0	0		
26							9.0	9.5
Mean	6.27	6.89	5.83	2.80	4.23	4.59	8.72	13.55
April 10, 1976							29.0	
21	9.0	11.0	11.0	10.0	9.0	7.0		
22	9.0	11.0	11.0	1.0	4.0	2.0	14.2	13.8
23	8.0	11.0	10.0	2.0	5.0	4.0		
24	8.0	11.0	11.0	0	3.0	1.0		
25	9.0	12.0	12.0	1.0	4.0	2.0		
26	13.0	13.0	12.0	2.0	4.0	4.0		
29	6.0	9.0	9.0	4.0	7.0	3.0	7.4	16.5
30	6.0	9.0	9.0	2.0	3.0	1.0		
Mean	7.25	10.88	10.63	2.75	7.13	3.0	16.87	15.15
May 1, 1976	6.0	9.0	9.0	2.0	5.0	1.0	4.2	16.3
2	9.0	10.0	9.0	1.0	4.0	1.0		
3	16.0	17.0	17.0	0	3.0	0		
4	12.0	11.0	15.0	3.0	4.0	4.0		
5	15.0	14.0	13.0	0	3.0	5.0		
6	8.0	12.0	15.0	1.0	3.0	2.0		
15	23.0	22.0	25.0	5.0	8.0	5.0		
16	25.0	23.0	26.0	7.0	8.0	7.0		
17	27.0	25.0	21.0	11.0	10.0	10.0		
18	20.0	18.0	22.0	9.0	14.0	11.0		
19	28.0	24.0	18.0	10.0	12.0	8.0		
20	20.0	19.0	20.0	10.0	13.0	4.0		
21	28.0	24.0	19.0	10.0	13.0	8.0		
28	22.0	19.0	20.0	11.0	13.0	16.0		
29	22.0	19.0	22.0	14.0	15.0	17.0	3.2	15.5
30	22.0	22.0	25.0	15.0	17.0	13.0		
31	35.0	3.0	24.0	14.0	17.0	18.0		
Mean	19.88	17.12	18.82	6.65	9.53	7.65	3.7	15.9
June 1, 1976	23.0	24.0	20.0	16.0	17.0	20.0		
2	27.0	24.0	16.0		19.0		2.2	4.5
15	19.0	19.0	23.0				8.8	14.2
21	33.0	29.0	22.0					
23	25.0	23.0						
Mean	25.4	23.8	20.25	16.0	18.0	20.0	5.5	9.35

TABLE 7. Air temperature and precipitation data at the Carman location, 1975

Date	May Rain mm	May Max (°C)	May Min	June Rain mm	June Max (°C)	June Min	July Rain mm	July Max (°C)	July Min	August Rain mm	August Max (°C)	August Min	September Rain mm	September Max (°C)	September Min
1	1.52	6.7	0		22.2	2.8		26.2	12.8		24.4	18.9		20.6	11.1
2	T	10.0	0	9.91	21.1	6.1		27.2	14.4		23.9	13.3	16.51	15.0	2.8
3		13.3	2.8		17.8	6.7		28.3	12.2		24.4	13.3		21.7	7.2
4		13.3	1.1	3.05	16.1	6.7	0.76	28.9	14.4		22.8	10.6		20.6	8.3
5		16.7	0		13.3	7.2		30.6	16.1		22.8	7.8	1.52	20.0	7.8
6		20.6	3.3		17.8	6.1	T	30.0	15.6		27.8	7.8	0.25	20.0	5.6
7		20.6	5.6	1.27	21.7	3.3		28.3	16.1	18.80	27.8	10.6		16.7	9.4
8		22.2	2.2	1.78	18.9	11.7		23.9	8.9		26.1	15.6		18.9	- 0.6
9		24.4	2.2	13.97	14.4	11.1		21.1	11.7		24.4	12.2		22.2	3.9
10		25.0	4.4	1.27	18.9	11.1	T	22.2	5.0	9.14	26.7	10.6		18.3	8.9
11		16.1	3.3		22.2	6.7		20.6	9.4		26.1	14.4		10.6	2.2
12		23.3	0	T	27.8	8.9		29.4	8.3		22.8	14.4		13.9	- 0.6
13	6.35	23.9	9.4	0.76	23.3	11.1		31.7	15.0		25.6	10.6		22.2	- 0.6
14		13.3	2.2		18.9	10.6		32.2	15.6		20.0	12.2		28.3	5.0
15		23.3	- 1.1		21.7	7.8		33.9	17.2	1.52	23.9	5.0		17.2	7.2
16	3.81	28.3	7.2		21.7	6.1		32.2	18.3		21.1	5.6		22.8	0.6
17	4.06	22.2	8.9		22.8	11.1	8.13	28.3	19.4		18.3	6.1	12.70	25.0	5.6
18	3.05	24.4	4.4		26.1	7.2	10.41	27.2	16.7		16.7	2.2	2.03	16.1	12.8
19	1.78	22.2	10.6	1.52	23.9	15.0	3.81	23.9	15.0		17.8	8.9	3.56	10.6	4.4
20	5.59	13.3	6.7	3.30	30.6	15.6	0.76	26.1	13.3	0.76	16.1	6.1		12.2	5.6
21	T	8.9	1.7	7.62	24.4	13.9	1.02	26.1	15.0		18.9	11.7		16.1	- 1.1
22	4.57	16.7	1.7	16.51	18.9	13.9		28.9	14.4	1.78	23.3	12.8		22.2	2.8
23	7.62	21.7	5.0	1.27	26.7	11.1		28.9	11.7		31.7	14.4		16.1	5.0
24	0.76	24.4	9.4		27.2	11.1		28.9	12.8	11.68	26.1	15.0		20.6	2.2
25		17.2	9.4		29.4	11.1		30.0	13.9	4.06	20.6	12.2		25.6	7.2
26		18.9	6.7		27.8	20.6		27.2	18.3		17.8	8.3		25.6	3.9
27		22.2	5.6	34.29	28.9	10.0		31.3	11.1		22.2	3.9		19.4	3.3
28	0.25	22.2	4.4	0.25	27.2	15.6		35.0	17.2		27.8	8.3		14.4	5.6
29		17.8	6.7	3.81	28.3	16.7		34.4	17.8	4.06	20.6	13.9	2.03	17.2	4.4
30	0.76	17.2	3.9		29.4	13.6		35.6	21.7		27.2	11.1		9.4	3.3
31		17.8	5.0				8.38	26.7	19.4		26.7	15.0			
	49.02	18.9	3.9	100.58	22.8	10.6	33.27	28.3	14.4	51.82	23.3	10.6	38.61	18.9	5.0

TABLE 8. Soil temperature and moisture data recorded at Winnipeg

Date	Soil Temperature						Soil moisture (GMC)	
	Maximum (°C)			Minimum (°C)				
	2.5 cm	5.0 cm	10.0 cm	2.5 cm	5.0 cm	10.0 cm	0-5 cm	5-10 cm
Oct. 2, 1975	17.0	14.0	14.0				16.0	13.8
3	15.2	13.1	13.0	8.0	9.0	11.0	15.8	24.8
6	15.8	12.9	12.9	7.0	8.0	8.8	15.2	27.8
7	15.0	13.8	13.8	10.0	10.5	10.5		
8	13.0	13.5	13.2	11.0	10.4	10.2	15.3	31.3
9	12.2	13.2	13.0	11.8	9.8			
10	12.0			8.0	9.5	10.0	23.0	25.8
12	12.8	11.0	10.0				19.0	28.3
14	12.8			5.0	6.0	6.8		
16				5.8	6.2	6.8	41.3	42.0
17				0	0.8	1.2		
20	12.8	10.5	9.2	5.5	6.5	7.2		
21	10.5			4.5	6.0	8.8		
22	8.8	7.5	6.1	1.5	3.8	4.2	32.8	38.4
23	8.8	8.2	7.2	2.8	4.0	5.2		
24	6.5	6.8	6.1	3.8	0	0.2		
27	3.5	2.8	3.0	2.3	3.0	3.0		
28	5.6	6.2	6.8	2.3	1.2	4.0		
29	6.5	4.0		0	1.2	1.8	30.2	35.4
30	5.2	5.0	4.3	0.8	2.8	3.5		
Mean	10.78	9.50	9.47	5.03	5.48	6.07	23.18	29.73
Nov. 3, 1975	11.2	7.0	5.2	4.2	4.3	4.5		
4	12.8	9.0	6.5	4.9	3.8	5.0		
5	14.3	9.8	6.6	2.6	5.0	5.2	26.8	32.0
6	14.2	11.8	8.8	5.8	4.8	5.0		
10	1.8	3.0	2.8	0	1.2	2.0	26.0	36.5
12	0.5	3.0	3.3	0.5	1.8	2.1		
14	1.5	3.5	3.2	0.5	1.9	2.0	12.0	33.0
17	3.0	4.5	3.1	- 2.0	- 0.5	- 0.8		
18	3.8	4.9	3.2	- 1.0	- 0.1	0		
19	2.2	2.8	2.8	0.2	1.0	0.8		
20	1.2	2.8	3.6	0	1.0	2.8		
21	1.0	1.8	2.4	- 1.0	1.0	1.8		
24	0	- 2.0	0.8	0	- 2.0	0.2		
26	0	0.3	0.2	0	0	0.1		
Mean	4.82	4.56	3.75	1.34	1.88	1.89	21.6	33.8
April 9				9.5	6.8	3.0		
12	13.2	14.0	12.0	12.0	8.0	3.0	23.0	41.0
15	16.5	14.8	12.3					
22	18.6	15.8	12.4	9.0	6.4	5.8	22.0	40
26				9.2	6.0	6.0	18.0	42
28	21.3	15.2	13.0	9.4	7.2	7.4		
29	16.2	14.0	12.0	9.6	8.0	8.4		
30				9.7	8.5	9.0		
Mean	17.16	14.76	10.34	9.91	7.27	6.09	21.0	41.0
May 2				6.2	9.0	11.0		
4				13.2	9.6	7.0		
5	18.2	16.0	13.0	5.5	6.0	7.5	13.0	45.0
7	21.5	15.3	15.0	9.0	8.0	9.0		
10				14.8	10.0	11.0	9.8	26.0
14	24.8	19.0	16.0	14.2	10.5	10.0		
19	25.8	23.0	19.0	15.7	14.0	14.0	9.0	18.0
20	25.8	22.0	18.0	18.6	14.0	13.0		
21	25.0	21.0	18.0	13.0	11.0	12.0		
25	32.0	25.0	21.0	19.5	16.0	14.0		
27	29.8	24.0	20.0	17.6	15.0	14.0		
28	26.0	24.0	22.0	19.8	15.1	18.0	11.3	20.4
30	26.2	25.0	22.5	20.0	18.0	15.5		
Mean	25.52	21.43	18.45	14.39	12.02	12.0	10.78	27.35
June 1, 1976				22.0	21.0	20.0	6.0	20.0
3				27.0	24.0	20.2	37.0	53.3
10	30.0	29.0	26.0					
21	32.0	28.0	24.0				47.0	37.0
Mean	31.0	28.5	25.0	24.5	22.5	20.1	30.0	36.77

TABLE 9. Air temperature and precipitation data at the Winnipeg location

Fall 1975

Date	October Rain mm	October Temperature Max (°C)	October Temperature Min	November Rain mm	November Temperature Max (°C)	November Temperature Min	December Rain mm	December Temperature Max (°C)	December Temperature Min
1		14	1		14	0		-16	-30
2		25	4		10	3		-16	-21
3		24	8		12	4		-9	-21
4		24	7		20	7		2	-9
5		22	9		22	3		4	-13
6		22	2		17	8		-10	-32
7		21	9		12	3		-9	-19
8		26	12		4	-1		-6	-17
9		24	6		6	-4		-3	-9
10		6	3		3	-2		-1	-19
11	2.45	8	6		1	-3		-19	-26
12		9	8		-1	-4		-21	-32
13	7.62	9	6		0	-11		-6	-23
14	1.02	7	6		6	-4		-23	-29
15	8.38	6	-1		11	-1		-17	-35
16	2.54	7	0		10	3		-18	-26
17		12	-2		8	-1		-22	-31
18		17	6		6	1		-14	-33
19		16	4		4	-1		-7	-14
20		14	4		0	-6		-8	-24
21		13	2		-1	-9		-8	-18
22		9	-1		-3	-10		-8	-17
23		8	0		1	-3		-8	-10
24		7	1		-11	-16		-8	-13
25	2.03	4	-4		-9	-19		-10	-17
26		7	-4		-8	-17		-10	-16
27		6	0		-7	-19		-6	-10
28		2	-3		-5	-9		-3	-6
29		4	-6		-5	-7		-4	-11
30		10	-1		-13	-18		-7	-17
31		9	1					-8	-13
Mean	4.02	13	3		3	-4		-10	-20

Spring 1976

Date	March Rain mm	March Temperature Max (°C)	March Temperature Min	April Rain mm	April Temperature Max (°C)	April Temperature Min	May Rain mm	May Temperature Max (°C)	May Temperature Min	June Rain mm	June Temperature Max (°C)	June Temperature Min
1		-12	-29		10	0		7	-3		27	11
2		-11	-13		6	1		4	-3		29	16
3		-12	-22		6	-2		10	-4		29	19
4		-18	-27		9	-5		18	4		30	19
5		-18	-31		12	1		10	-3	8.13	27	18
6		-8	-23		14	2		6	-5	29.21	27	17
7		-4	-22		12	0		16	-4		19	14
8		-10	-16		16	-1		21	7	3.05	24	13
9		-12	-16		18	4		27	7	12.95	27	12
10		-13	-19		17	2		24	7		27	16
11		-12	-19		11	-3		20	1		27	13
12		-12	-19		18	2	2.54	23	7	30.48	27	16
13		-7	-22	2.79	21	3		19	7	10.16	23	13
14		-9	-19		21	12	3.30	21	6	3.30	17	11
15		-7	-18		17	2	2.54	21	10		14	8
16		-10	-24	3.81	13	7		19	7	12.95	18	4
17		-1	-19	3.81	12	6		19	2		18	10
18		4	-12	3.81	6	2		21	8		19	7
19		3	-9	0.50	6	-2		26	10		25	10
20		4	-24		6	0		22	7		29	13
21		-11	-22		11	-2		19	6		30	14
22		1	-14		11	1		22	4		23	12
23		4	-4		14	-1		23	4		28	16
24		1	-5		12	0		23	3	5.33	28	17
25		1	-13		14	-2		26	6	2.29	19	13
26		1	-2		12	-2		27	14	6.35	19	11
27		2	-8		11	-3		19	7		23	10
28		3	-2		13	-1		22	7	3.05	24	10
29		2	-3	1.27	17	4		26	8		22	13
30		6	-3		12	3		27	9		25	13
31		6	-4					27	11			
Mean		-5	-16	2.67	13	1	2.79	20	5	10.60	24	13