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Title: EFFECT OF A PRE-IRRIGATION PERIOD ON THE ACTIVITY OF ETHOFUMESATE APPLIED TO DRY SOIL

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Applications of ethofumesate in Oregon have been observed from previous research and from commercial use to be less effective when applied to dry soils, even if subsequent precipitation occurred within a few days. Two field studies were established in the summer of 1979 using sweet corn (*Zea mays* L. 'Jubilee') and winter wheat (*Triticum aestivum* L. 'Stephens') as bioassay species to determine the effect of dry soil on ethofumesate efficacy. Applications of various rates of the herbicide were made to soils of approximately 2 and 30% w/w soil moisture. After 2 to 4 days, all soils were irrigated for stand establishment and maintained at a high moisture level. Ethofumesate, at most rates, was significantly less effective on both corn and wheat when applied to dry soil than to wet soil.

Two greenhouse studies were conducted using spring wheat (*Triticum aestivum* L. 'Fielder') bioassays. One employed five soil moisture levels, 2, 5, 9, 15, and 36%, and all soils were wetted to field capacity 4 days after herbicide application. The other study

used 2 and 12% moisture contents and soils were wetted 0, 2, and 4 days following herbicide application. The first study showed a general decrease in herbicide activity with decreasing water content with a greater than expected drop in activity at 15% moisture. This drop in herbicide activity is believed to be the result of the soil surface drying after application.

The second study showed substantially greater herbicide activity at 12% moisture than at 2% moisture. The ethofumesate was incorporated in this study, eliminating the effect of surface drying. An increase in herbicidal activity was apparent as the length of time between herbicide application and wetting increased from 2 to 4 days for the 2% moisture soils. The reason for this effect is not clear.

Soil samples (50 g, air-dried equivalent) at 2 and 20% soil moisture were treated with 484 μg of ethofumesate. The herbicide was extracted from the soils with hot methanol 0, 2, 4, 6, and 12 days after application. A gas chromatography analysis for ethofumesate revealed no loss in the amount of herbicide applied to wet soil over the 12-day period while in the dry soil, the amount extracted after 12 days was 10% of the amount extracted at 0 days. These data suggest chemical degradation of ethofumesate as the most likely mechanism for the activity loss in dry soil.

EFFECT OF A PRE-IRRIGATION PERIOD ON THE ACTIVITY OF ETHOFUMESATE APPLIED TO DRY SOIL

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Typed by Gloria M. Foster for David McAuliffe

DEDICATION

This thesis is dedicated to my wife, Donna, for her love, patience, and support throughout my graduate studies.

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EFFECT OF A PRE-IRRIGATION PERIOD ON THE ACTIVITY OF ETHOFUMESATE APPLIED TO DRY SOIL

INTRODUCTION

Ethofumesate is a highly selective herbicide in ryegrass (*Lolium* spp.) and sugarbeets (*Beta vulgaris* L.) (5, 20, 23). The ability of this herbicide to control many winter annual grasses such as rattail fescue (*Festuca myuros* L.), annual bluegrass (*Poa annua* L.), and volunteer small grains makes ethofumesate a useful tool for grass seed growers in Oregon (14).

As with most soil-applied herbicides (2, 4, 6, 8, 16, 24, 27), adequate soil moisture is required for satisfactory ethofumesate activity. Hartley (11), using *Hordeum marinum* L. as an indicator species, found that the activity of ethofumesate decreased as the soil moisture at the time of application decreased from 50 to 10% w/w. Similarly, Ostrowski and Reisler (18) found less ethofumesate activity in air-dried soil than in soil at 15% moisture content using oats (*Avena sativa* L.) as indicator plants. They concluded that sufficient soil moisture was needed to increase the availability of the ethofumesate to the emerging shoots and that adsorption of the herbicide was probably causing the lack of activity in dry soil.

In a comprehensive study on the behavior of ethofumesate in soil, van Hoogstraten, et al. (12) concluded that the molecular structure of ethofumesate suggests the availability of negative charges for ionic binding and the possibilities for hydrogen bonds and van der Waals-London interactions with the soil particles. But they also reported that Reisler established a value of only 6.5 for the equilibrium constant of ethofumesate using the empirical Freudlich equation under the same conditions that gave a value of 22 for diuron. This suggests that adsorption of ethofumesate may not be a major factor in determining its activity.

In Oregon, Lee[1] has observed a loss in ethofumesate activity when application of the chemicals are made to dry soil, even though rain falls within a few days. This effect may be similar to results seen in studies by Hance and Embling (9) who found that concentrations of simazine, metribuzin, and linuron in the soil solution were shown to be substantially less when sprayed on dry soil and wetted 24 h later than when sprayed on moist soil. The spray solutions were thought to be drawn into the dry soil particles and rendered inaccessible to added water.

Soil moisture also can influence the rate of degradation, volatilization, or leaching of a herbicide (7, 22, 25). Hargrove and Merkle (10) treated soils with alachlor at five different moisture contents and three temperatures, 22, 38, and 46 C. Loss of alachlor was greatest at the lowest moisture content and the highest temperature. Analysis by gas chromatography showed that alachlor loss was due to breakdown under these conditions and was not due to volatilization, leaching, or strong adsorption. They attributed this loss to the increased acidity of the remaining water in a soil of low moisture

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[1]Lee, W.O. 1979. Personal communication. Oregon State University, Corvallis, Oregon.

content as described by Mortland and Raman (17). Acid soil solutions also have resulted in an increased chemical degradation of a number of s-triazine herbicides (3, 21).

The objectives of this study were (a) to measure the influence of a time interval between application of ethofumesate to dry soil and wetting of the soil and (b) to elucidate the reasons for losses in activity.

MATERIALS AND METHODS

Field Studies. Two sets of experiments were established at the Oregon State University Hyslop Research Farm near Corvallis, Oregon during 1979. The purpose of the research was to compare the activity of ethofumesate when applied (a) to dry soil followed by a 48- to 96-h "dry period," and then irrigated, or (b) to a wet soil followed soon after with additional irrigation. The first set of trials was established in mid-July in 1979, using sweet corn (*Zea mays* L. 'Jubilee') as the indicator plant. One corn trial included a dry period of 48 h and the second had a 72-h dry period. The second set of trials was established in late September, using winter wheat (*Triticum aestivum* L. 'Stephens'). The dry periods in the two trials were 48 and 96 h.

The soil at Hyslop Farm is a Woodburn silt loam, a member of the fine, silty, mixed, mesic, family of Aquultic Argixerolls. Soil moisture content in both trials was determined gravimetrically before and after irrigation from samples taken throughout the experimental area. The amount of irrigation water applied also was determined through the use of catch-cans. Soil moisture levels are expressed as percent water by weight.

a. Corn trials. The corn trials had received less than 18 mm of precipitation in the four weeks prior to herbicide application. Soil moisture in the top 2 cm was 2.0 ± 0.5% w/w in the dry soil. After plots had received an average of 1.1 cm of irrigation prior to "wet soil" herbicide application, soil moisture was 30 ± 2% w/w in the top 2 cm.

Soil in the experimental area on which the corn trials were conducted had an organic matter content of 2.45% and a pH of 5.0. The land was disked and fertilized with 560 kg/ha of 16-20-0 before planting the corn. Corn was planted with "Planet Jr." planters. Seeding depth was 2.5 cm at a seeding rate averaging 30 seeds/m of row. Row spacing was 30 cm.

Plot size was 1.8 by 6 m with eight treatments in each trial. Experiments were arranged in a randomized complete block design with five replications. Treatments consisted of four rates of ethofumesate: 0, 0.84, 1.13, and 1.40 kg a.i./ha, applied with a bicycle-wheel plot sprayer using 280 L/ha of spray solution. The sequence of treatments was as follows: ethofumesate was applied to dry soil followed by 4 h of irrigation over the entire experimental area, either 48 or 72 h after application. The herbicide was then applied to additional plots (wet treatments), followed by an additional 4-h irrigation over all treatments. The entire experimental area was maintained in a moist condition until harvest.

Measurements of ethofumesate activity were made by visually evaluating corn growth 1 month after planting and by taking fresh and dry weights of the corn harvested 5 weeks after planting. The center 1.2 m of each plot were cut by hand. Fresh weights were determined immediately after cutting and dry weights were measured following 5 days of drying at 50 C.

b. Wheat trials. Winter wheat trials were established after a period of four weeks in which precipitation was less than 12 mm. Soil moisture was 2.8 ± 0.6% prior to the initial irrigation and 28 ± 5% following an irrigation of 1.3 cm of water.

Soil in the experimental area where the wheat trials were conducted had an organic matter content of 2.85% and a pH of 5.4. Land was prepared for planting in the same manner as in the corn trials. The fertilizer rate was 224 kg/ha of 16-20-0.

Wheat was planted with "Planet Jr." planters. Seeding depth was 2.5 cm at a seeding rate averaging 44 seeds/m of row. Row spacing was 30 cm.

The two wheat trials had 48-h and 96-h dry periods. Plot size for each trial was 1.8 by 6 m with 10 treatments arranged in a randomized complete block design with five replications. Rates of ethofumesate were 0, 0.25, 0.50, 0.75, and 1.0 kg/ha. Visual evaluations and fresh and dry weight measurements were made in the same manner as with the corn, except fresh weights were taken 7 months after planting. Plots were harvested with a small-scale swather with a 0.85 m header.

c. Statistical analysis. All field data were analyzed in a factorial arrangement with three levels, including replications, soil moisture levels, and herbicide rates. A least significant difference value (LSD) was calculated for each evaluation method in each of the field trials by the equation $LSD = R\ (t_{05}\ \sqrt{\frac{2\ ems}{n}}\ )$ where R is a conversion factor that allows comparisons between the most divergent means in a Duncan's multiple range test (15). This value changes with the number of means that are compared and the degrees of freedom in the error term. The LSD was used as a test of significance for differences among all means. Prior to analyzing the visual ratings, the data were transformed by angular transformation (arcsine $\sqrt{\%/100}$) (15).

Greenhouse Studies. All greenhouse experiments were conducted at the Oregon State University greenhouses in Corvallis, Oregon between October 1979 and July 1980. The greenhouses were maintained at approximately 24 C day and 21 C night temperatures with no supplemental lighting. Spring wheat (*Triticum aestivum* L. 'Fielder') was used as the bio-indicator plant. Plastic pots, 10 by 10 by 10 cm, were employed in all experiments.

Twelve wheat seeds were placed on a sandy loam soil with an organic matter content of 3.65% and a pH of 6.2. The seeds were covered with 2 cm of a Woodburn silt loam, with an organic matter content of 2.9% and a pH of 5.2, which had been screened through a 3- by 3-mm mesh sieve. The primary herbicide-soil interaction was expected to occur in the silt loam soil; the sandy loam soil was needed merely to facilitate emergence and growth of the wheat plants. Ethofumesate was surface-applied with a variable-speed overhead sprayer, calibrated to deliver 285 L/ha of spray solution with a TeeJet 80015 E nozzle tip at 2.25 kg/cm^2 of pressure.

Soil moistures below field capacity in the various experiments were obtained by air-drying the Woodburn silt loam to a moisture of 2.0 ± 0.2% and adding measured amounts of water. The water was sprayed onto the soil as it mixed in a soil tumbler. After mixing for about 10 min, the soil was again screened, hand-mixed, and allowed to set for 24 h. Soil samples were taken at the time of ethofumesate application to determine moisture contents. For the soil moisture that approximated field capacity (36 ± 3.5%), dry soil was placed in pots and subirrigated for 1 h prior to treatment.

The first greenhouse experiment was conducted to determine the influence of various soil moisture levels on the activity of ethofumesate. Five soil moisture levels were employed, 2, 5, 9, 15, and 36%, with 150 g (air-dried equivalent) of each as treated soil at each level. The flowable formulation of ethofumesate was applied at 0, 0.15, 0.30, and 0.60 kg a.i./ha to soil at each moisture content. The experiment was arranged in a randomized complete block design with four replications.

Immediately following application of the herbicide, the pots were covered with aluminum foil to maintain the soil moisture levels until the pots were irrigated. No determination of moisture content was made just prior to irrigation. The pots were subirrigated 4 days after spraying and the soil surfaces were kept moist until harvest.

Ethofumesate activity was evaluated 4 weeks after planting by determining fresh and dry weights of the aboveground portions of the wheat plants and by visually rating each treatment against their respective controls.

A second greenhouse experiment was conducted to determine the effect of the length of the dry period on ethofumesate activity and to ascertain the effect of drying on activity loss.

Two soil moisture levels were used, 2 and 12%, with three rates of ethofumesate applied, 0, 0.2, and 0.4 kg/ha. For each rate and moisture level, the pots were subirrigated either 0, 2, or 4 days after application. The experiment was arranged in a randomized complete block design with four replications.

A base soil was used as in the prior experiment. Again, 12 wheat seeds were used per pot. Ethofumesate applications were made by placing enough Woodburn silt loam to cover each of the 12 pots with 150 g (air-dried equivalent) in a tray with an area equal to that of the 12 pots. After the trays were sprayed with their respective rates of herbicide, the soil was blended to incorporate the ethofumesate. The treated soil was used to cover the seeds in each pot. The pots were covered with aluminum foil for the length of their respective dry periods.

Evaluations were made by measuring fresh and dry weights and visually rating herbicide effects in each pot.

The fresh and dry weight data obtained did not allow an analysis of variance to be completed without a transformation to stabilize the variances within each treatment. A $\log_{10}$ transformation was used in both greenhouse experiments. An LSD was calculated in the same manner as in the field trials; however, this value can be used to make comparisons only among the means of the transformed data.

Each of the two greenhouse experiments was repeated once with similar results (Appendix Tables 24, 25, 32, 33). The experiment which tested the effect of various soil moistures on ethofumesate activity also was run using Jubilee sweet corn as a bioassay with similar results (Appendix Tables 26, 27).

Ethofumesate Persistence in Soil. A study was conducted to determine the quantity of ethofumesate present in moist and dry soil over time. Woodburn silt loam soil (50 g, air-dried equivalent) was placed in lids of plastic petri dishes, 11 by 11 by 3.5 cm. Treatments consisted of two soil moisture levels, 2% and 20%, sprayed with 0.4 kg/ha of ethofumesate (approximately 484 μg of ethofumesate per lid).

Immediately after spraying, the soils were covered with the petri dish bottoms to maintain moisture levels. The inverted petri dishes were placed in a dark growth chamber at a constant temperature of 20 C.

The experiment was arranged in a randomized complete block design with three replications. Additional petri dishes were employed as checks in the analysis and as a means of determining moisture changes over the 12-day treatment period. Over this period, the moisture content of the 20% treatments dropped significantly. After 6 days, the moisture content was 17 ± 0.5% and after 12 days it was 11 ± 2%. The 2% moisture level remained constant throughout the experiment.

Ethofumesate was extracted from the 50-g soil samples at both moisture levels, 0, 2, 4, 6, and 12 days after application, using a modification of the method of Whiteoak, et al. (26).

Water was added to each soil sample, 22.5 ml to dry samples and 12.5 to wet samples, and allowed to stand for 20 min. Each sample was refluxed briskly for 45 min in 170 ml of methanol. The samples were cooled and filtered into graduated cylinders. The filtered soil was washed with methanol until a final volume of 190 to 200 ml was reached. The filtrate was added to a 1000-ml separatory funnel containing 350 ml of water and 25 ml of saturated sodium sulfate. To this, 400 ml of dichloromethane was added. The separatory funnel was agitated well to mix the various chemicals.

Two layers formed in the separatory funnel, an aqueous layer and the heavier dichloromethane on the bottom containing the ethofumesate. The bottom layer was percolated through anhydrous sodium sulfate. Each 400-ml sample was boiled down and concentrated to 10 ml using a steam plate and a stream of dry nitrogen. The ethofumesate concentration was assayed using a hydrogen flame ionization gas chromatograph with a 2-m by 2-mm i.d. glass column. The packing was 1.5% Carbowax 20M, 1.5% OV 17 on 60-80 mesh Gas Chrom Q. The column temperature was 210 C with a gas flow of 22 ml/min. Amounts of intact ethofumesate remaining in the soil at each sampling date were determined by comparing peak heights with a standard curve.

Recovery of ethofumesate extracted from soil was at least 80% in studies reported by Whiteoak, et al. (26). Initial extractions of both the wet and dry soils yielded from 68 to 83% of the 484 μg applied to each petri dish lid. The dry soils averaged 72% ethofumesate recovery while the wet soils averaged 78% recovery.

The data were analyzed using a factorial arrangement with three levels. All the data were transformed by taking the $\log_{10}$ of each value and an LSD was calculated for the transformed data. This experiment was repeated with similar results (Appendix Table 36).

RESULTS AND DISCUSSION

In all field trials, ethofumesate was less effective when applied to dry soil than when applied to wet soil, even though all soils were brought to a uniform moisture level in 96 h or less. At each rate of herbicide, yields of the aboveground portions of the corn were reduced more when ethofumesate was applied preemergence to a wet soil than to a dry soil, although not all differences were significant (Table 1). At the 1.4 kg/ha rate, applications to dry soil were 25 to 35% less effective than applications to wet soil as measured by corn growth. The length of the dry period did not consistently affect differences between wet and dry soil applications.

Winter wheat growth also was affected less by ethofumesate treatments to dry soil than to wet soil. Differences in wheat growth between wet and dry soil applications were evident only for rates above 0.28 kg/ha. At the 0.84 and 1.13 kg/ha rates, effectiveness of ethofumesate was 25 to 40% less with applications to dry soil than to wet soil (Table 2).

Results from the field trials were substantiated by the first greenhouse study. A comparison of the activity of ethofumesate applied to soils of various soil moisture levels indicates an increase in wheat injury with increasing water content (Figure 1). The fresh weight of wheat from pots sprayed at 2% soil moisture content yielded 83, 41, and 19% of their untreated checks for the 0.15, 0.30, and 0.60 kg/ha rates of ethofumesate, respectively. At

Table 1. Growth of sweet corn treated preemergence with ethofumesate on wet and dry soil in the field, expressed as percent reduction in corn growth.

Herbicide Rate	Soil Moisture Level[a]	Fresh wt yield		Visual Evaluations	
		Length of the dry period[b]			
		48 h	72 h	48 h	72 h
(kg/ha)		%			
0.84	Dry	0	18	27	16
	Wet	20	20	67	72
1.13	Dry	11	9	30	40
	Wet	16	37	72	81
1.40	Dry	6	3	45	45
	Wet	31	37	69	79
LSD (05)		15	22	13	13

[a]Dry soil = 2 ± 0.5% w/w for top 2 cm; wet soil = 30 ± 2% w/w for top 2 cm.

[b]Dry period refers to length of time from application to dry soil to initiation of overhead irrigation.

[c]$LSD = R\left(t_{05}\sqrt{\frac{2\ EMS}{5}}\right)$ R = 1.12 for 6 means.

Table 2. Growth of winter wheat treated preemergence with ethofumesate on wet and dry soil in the field, expressed as percent reduction in wheat growth.

Herbicide Rate	Soil Moisture Level[a]	Fresh wt yield		Visual Evaluations	
		Length of the dry period[b]			
		48 h	72 h	48 h	72 h
(kg/ha)		%			
0.28	Dry	7	0	25	17
	Wet	7	0	25	26
0.56	Dry	22	0	36	21
	Wet	13	25	32	38
0.84	Dry	17	15	41	36
	Wet	44	43	55	50
1.13	Dry	31	29	47	40
	Wet	59	73	64	75
LSD (05)[c]		20	18	13	14

[a]Dry soil = 2.8 ± 0.6% w/w for top 2 cm; wet soil = 28.0 ± 5% w/w for top 2 cm.

[b]Dry period refers to length of time from application to dry soil to initiation of overhead irrigation.

[c]$LSD = R\left(t_{05}\sqrt{\frac{2\ EMS}{5}}\right)$ R = 1.15 for 8 means.

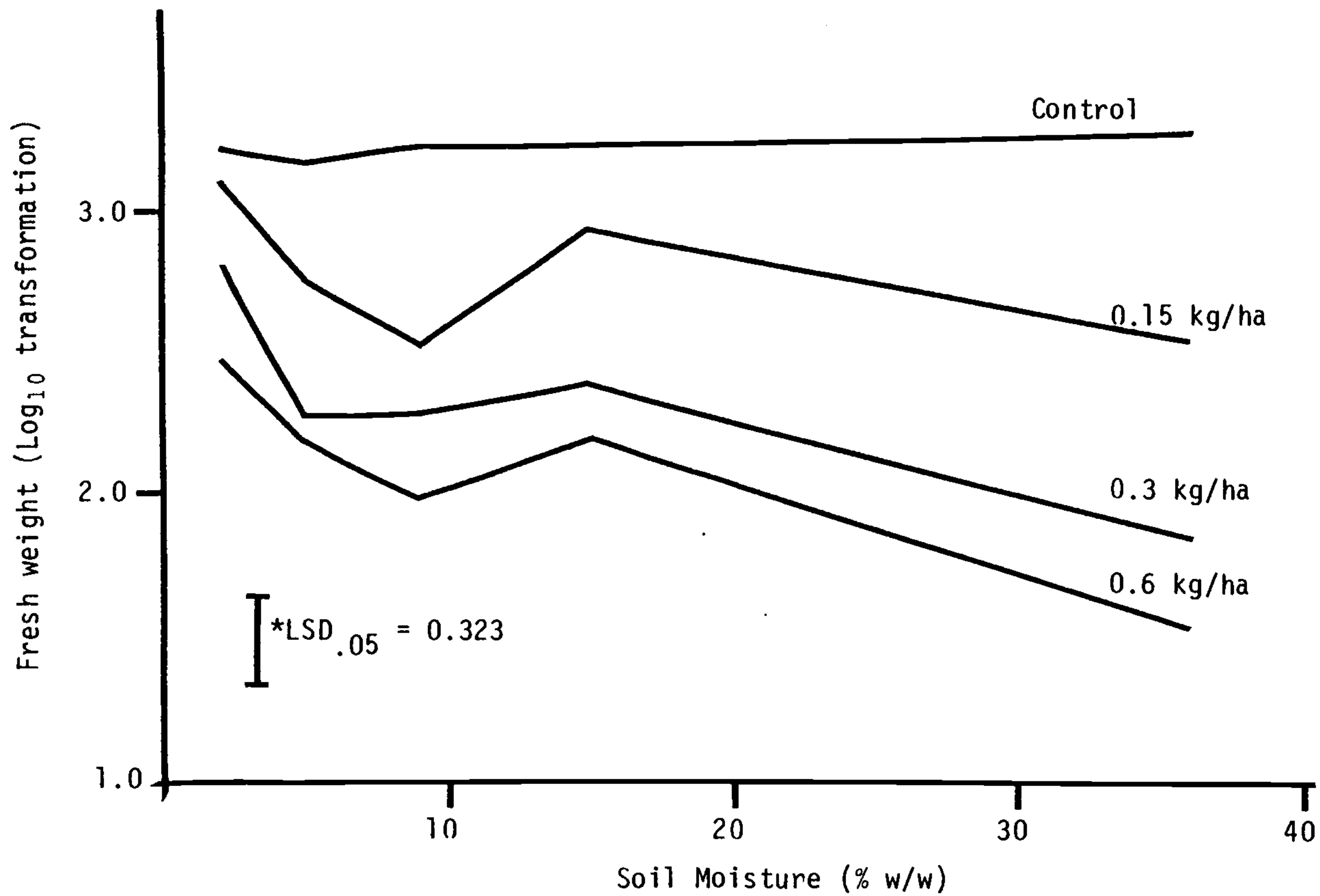

Figure 1. Fresh weight of winter wheat treated with ethofumesate at five moisture levels.

*LSD = R $\left(t_{05}\sqrt{\frac{2\ EMS}{4}}\right)$ R = 1.23 for 20 means.

the 36% soil moisture content, wheat yields were only 20, 5, and 2% of their untreated checks for the respective rates.

The sharpest increase in activity occurred when soil moisture increased from 2 to 5%, although at the high rate of ethofumesate, this difference was not significant. Ethofumesate activity generally increased as moisture levels increased from 2 to 9%. However, an unexpected drop in herbicide activity was evident at the 15% soil moisture level. This activity loss is likely the result of surface drying of the pots at 15% moisture. The pots were covered in an effort to maintain moisture levels, yet moisture loss through evaporation did occur. The most noticeable loss was from the soils at 15% moisture, but no quantitative measurements were made.

The second greenhouse study was conducted in an effort to determine the reason for the activity loss at the 15% moisture level. With incorporation of ethofumesate into the top 2 cm of soil, herbicide activity was much higher at the 12% moisture level (Table 3) as compared to activity from surface-applied ethofumesate at 15% moisture in the previous experiment. Surface drying of the soil at 12% moisture did occur but an adequate moisture level was maintained below the surface. Although these data seem to be contradictory, they might be explained by the effect of soil drying on the herbicide.

The data might suggest a physical impedence of the ethofumesate when surface applications were made to soils of 15% moisture and

Table 3. Influence of length of dry period and soil moisture on the activity of ethofumesate incorporated to 2 cm, expressed as percent reduction in wheat growth in the greenhouse.

Irrigation days after spraying	Ethofumesate rate	Reduction in wheat fresh wt. Soil moisture level 2% w/w	12% w/w
	(kg/ha)	%	
0	0.2	98	90
	0.4	100	99
2	0.2	50	98
	0.4	83	100
4	0.2	70	99
	0.4	94	99
LSD (05)[a]		7	

[a]$LSD = R\left(t_{05}\sqrt{\frac{2\ EMS}{4}}\right)$ R = 1.18 for 12 means.

allowed to dry. A soil initially moistened to about 15% moisture has a soil matrix structure such that the soil particles are sufficiently spread and there is sufficient water to allow the movement of the herbicide molecules between the particles. As the surface moisture declines, the spacing between the colloids decreases, entrapping the ethofumesate molecules. The herbicide is then under the same chemical influences as when applied to dry soil with the additional reduction in activity resulting from entrapment. Release of intact ethofumesate molecules is then probably too slow to be effective following wetting. Soils at 5 to 9% moisture would not have sufficient water to expand the matrix and allow ready movement of the herbicide molecules, thus reducing the effect of soil drying.

Although no clear effects of length of dry period were evident in the field studies, the greenhouse study showed an unexpected increase in herbicide activity with an increase in the length of the dry period. Ethofumesate activity from both the 0.2 and 0.4 kg/ha rates applied to dry soil and wetted immediately was comparable to applications made to wet soil (Table 3). As the length of the dry period increased to 2 days, ethofumesate activity diminished, as seen in the field. Yet, ethofumesate applied to dry soil with a 4-day dry period was actually more effective following irrigation than when the dry period was 2 days. The reason for this difference is not known. Possibly, some degradation product may result from the application of ethofumesate to dry soil that is toxic to wheat and more readily available for uptake. The product may be more water soluble or less affected by the soil colloids and more likely to be absorbed. The confines of the greenhouse pots and the system of irrigation would make this effect more noticeable than in the field trials.

In the ethofumesate persistence study, no loss of ethofumesate occurred from the wet soil over the 12-day period but the herbicide disappeared rapidly from the dry soil (Figure 2). After 12 days, only 10% of the ethofumesate remained in the dry soil. The rate of disappearance closely followed first-order kinetics. These results suggest that the reduction in ethofumesate activity at low moisture levels is the result of an actual disappearance of the herbicide from dry soil.

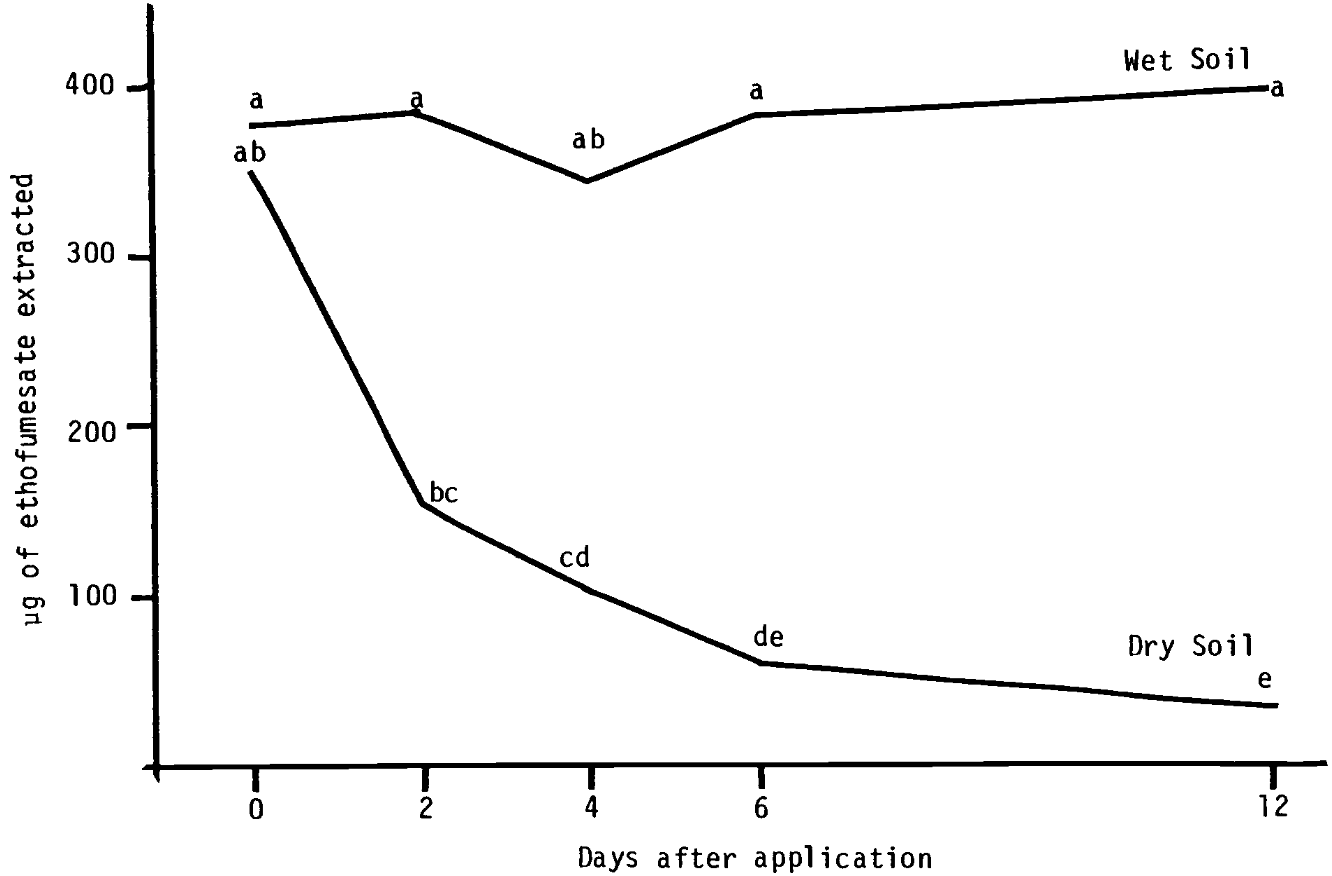

Figure 2. Rate of disappearance of ethofumesate from wet and dry soil in the greenhouse. Data points with the same letter are not significantly different at the 5% level.

CONCLUSIONS

The activity of ethofumesate used commercially in ryegrass fields in Oregon has been much lower when applications have been made in the fall to dry soil. The loss in activity occurred despite rainfall that followed 3 or 4 days after application. This reduction in ethofumesate activity was verified by both field and greenhouse trials conducted in this study.

Since the ethofumesate was surface-applied in both the corn and wheat trials in the field, various modes of loss could be responsible for the diminishing activity. These include volatilization, photodecomposition, microbial degradation, irreversible binding on or within the soil colloids, and chemical degradation.

Ethofumesate has a low vapor pressure, 6.45×10^{-7} mm Hg at 25 C (12), which makes appreciable vapor loss in 2 to 4 days rather unlikely. Further, several studies (7, 13, 19) have shown that vapor loss is more likely from a wet soil than from a dry soil.

Photodecomposition could be possible in the field studies, although reasons for more rapid loss from dry soils than from wet ones by this means are not readily apparent. The greenhouse studies were designed to prevent photodecomposition by covering the soil surface with foil. The greenhouse results were similar to those in the field, leading us to believe that photodecomposition is not a significant factor.

Although van Hoogstraten, et al. (12) have indicated that ethofumesate is likely to be degraded in soils through microbial activity, appreciable loss would not be expected in such a short period of time. Even if microbial degradation did occur, losses should be greater in the moist soils than in the dry ones.

Herbicides have been shown to be adsorbed more tightly to dry soil than to wet soil (4, 8, 24). Our original hypothesis was that this was the most likely explanation for reduced activity of ethofumesate when applied to dry soil. The fact that herbicidal activity was not restored when moisture was added, might be explained by strong adsorption on the dry soil surface or within the soil matrix that could not be reversed by water. This possibility is supported by work by Hance and Embling (9) who showed that the spray solutions of simazine, metribuzin, and linuron were likely drawn into dry soil particles, becoming inaccessible to water when the soil was subsequently wetted. This possibility has not been disproved by our studies; however, in the ethofumesate persistence studies, the soils were refluxed with methanol for 45 min. This would seem to be adequate for extracting even strongly bound ethofumesate.

A remaining possible explanation for the rapid loss from dry soils is through chemical decomposition. van Hoogstraten, et al. (12) suggest that ethofumesate might hydrolyze to a 2-keto or a 2-hydroxy product. At the lower soil moisture levels, the water film around the soil colloids would be much more restricted. This could conceivably enhance chemical breakdown in atleast two ways: (a) Adsorption of the herbicide may be increased under these conditions, which may cause the herbicide to be more susceptible to hydrolysis. For example, Armstrong and Chesters (1) have shown that adsorption catalyzes hydrolysis of chloro-*s*-triazines. (b) The pH of a water film closely adhering to a soil colloid is likely to be considerably lower than that of a more extensive solution in a more moist soil (17). The lower pH might cause rapid hydrolysis of the ethofumesate. Hargrove and Merkle (10) demonstrated a degradation product of alachlor when the herbicide was applied to soil at 0% relative humidity and 36 or 46 C. This product was apparently the result of the decomposition of alachlor by acidic soil water.

No degradation products of ethofumesate were detected in the gas chromatography work; however, only the dichloromethane fraction was analyzed. The retention time of possible breakdown products was not known and no special attempts were made to detect them. Such products could have been present in the dichloromethane but not detected, lost during the percolation through anhydrous sodium sulfate, discarded in the aqueous phase, or lost by volatilization during refluxing.

Further research is required to clarify the mechanism of rapid loss of ethofumesate activity in dry soils. Whatever the cause, the efficacy of this herbicide clearly can be seriously reduced when applied under dry conditions commonly encountered in the field.

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APPENDICES

LITERATURE REVIEW

The fate of a herbicide applied to soil depends on the physical and chemical characteristics of the soil, the physical and chemical characteristics of the herbicide itself, and the biotic and abiotic environmental conditions at the time of herbicide application (2, 11, 17). One important characteristic of the soil that greatly influences herbicide activity is soil moisture. If the possible fates of a soil-applied herbicide are considered, the importance of soil moisture is readily apparent.

Soil moisture has been shown to influence herbicide activity by a number of researchers (19, 27). Upchurch (28) found diuron to be more active at higher soil moistures than at low. Similarly, Grover (12) demonstrated that nearly three times as much simazine was needed at 30% soil moisture as at 60% moisture to give similar reductions in oat seedling growth. Conversely, the loss of trifluralin has been shown to increase through vapor loss and degradation as moisture levels increased (27). EPTC is also lost more rapidly by volatilization from a moist soil (1, 9).

Soil moisture can affect herbicide activity in a number of ways. Such effects include alterations in microbial activity, in herbicide transport within the soil, and in the rate of herbicide chemical degradation in soil. Soil moisture levels also significantly influence the amount of adsorption and desorption that occurs between applied herbicides and the soil colloids.

Many pesticides have been shown to be more readily adsorbed at low soil moistures than at high moistures. As previously mentioned, EPTC is lost more rapidly from moist soil than from dry soil. This results from the ready binding of EPTC with the soil constituents under dry soil conditions. But as the moisture level increases, the herbicide cannot compete with the water for adsorptive sites and is desorbed and subject to vapor loss. Atrazine, 2,4-D, simazine, chlorpropham, and diuron also have been demonstrated by various researchers to be adsorbed to a greater extent at low soil moistures than at high (5, 12, 13, 21, 23). Yaron and Saltzman (30) adjusted the moisture levels of various soils by placing the soils in containers with saturated salt solutions, giving a range of relative humidities. Using this technique, they found a significantly greater amount of the insecticide parathion to be adsorbed under low R.H. values than under high values. They also showed a decrease in adsorption with increasing R.H. as a result of water competition for the adsorptive sites.

A major consideration in the adsorption of a herbicide to dry soil is the ability of the herbicide to desorb from the colloidal surfaces once the water content has increased. Desorption of the herbicide is necessary to release the chemical into the soil solution in order for it to be active as a herbicide. The ability of a chemical to desorb is, as Bailey and White (2) indicate, related to the binding energy of the adsorbent-adsorbate complex. This energy depends on the pesticide and soil properties.

The effect of increased adsorption and reduced desorption was dramatically demonstrated by Hance and Embling (15). Hance (14) had previously found more metribuzin in a soil solution extracted from soil that was wet (12% w/w moisture) than from one that was air-dried. The differences, however, were non-existent if the soil was left in a slurry state for 24 to 48 h. In this study, Hance used a 1:1 soil-to-water ratio and centrifuged the slurry to obtain his extract. He found the opposite result for simazine and suggested that the simazine was more soluble and more readily adsorbed in the wet soil than in the dry. Again, any difference that occurred disappeared in 24 h.

In a later study, Hance and Embling used a pressure membrane apparatus to obtain an extract. Only 10 ml of water were added to 40 g of soil (air-dried basis) giving a 20% w/w moisture content. Extracts were taken up to 96 h after herbicide applications for soils that were sprayed wet, sprayed dry and wetted immediately, and sprayed dry and wetted 24 h later. In this study, linuron, metribuzin, and simazine, all in the wettable powder formulation, exhibited a sharp decrease in concentration in the soil solution when applied to a dry soil and wetted 24 h later. The differences between wet soil and dry soil applications remained over the 96-h experimental period. As a result, the concentration of simazine and metribuzin in the 24-h dry soil was half that of the wet soil. The concentration of linuron in the soil solution applied to dry soil and wetted 24 h later was only one quarter of the concentrate for treatments made to moist soil. In all cases, the concentration of the 24-h dry treatments tended to increase for the first 6 to 24 h after wetting. However, very little or no increase was recorded from 24 to 96 h. Simazine, in the flowable formulation, also showed an initial decrease in concentration for the 24-h dry soil, but over the 96-h period, these differences disappeared.

These data give some indication as to the strength of adsorption of the various herbicides and illustrates the time lag involved in the desorption process with the possibility that much of the applied chemical may have formed more permanent bonds with soil constituents. The slow release or permanent adsorption can then dramatically reduce the biological activity of the herbicides.

The two experiments also demonstrate the inaccurate picture slurry extractions draw of actual field conditions. The slurry technique resulted in a rapid reduction in the difference between the concentrations of metribuzin in the soil solution for applications of the herbicide made to wet and dry soil. This was not the case for the pressure membrane technique and suggests the greater quantity of water resulted in a greater partitioning of the metribuzin into the soil bulk solution and an increasing competitive ability by the number of water molecules for adsorptive sites.

Graham-Bryce (8) demonstrated the influence of soil drying on the adsorption and subsequent desorption of the insecticide disulfoton. Using two soil types with differing adsorptive capacity, he found that desorption followed well the curve for adsorption when desorption occurred immediately. However, if the soil was allowed to dry at 20 C for 48 h after application, desorption was more difficult. In a similar study, the desorption of the substituted urea herbicide, N'-(4-chlorophenoxy)-phenyl-N,N-dimethyl urea, was more difficult as more of the chemical was removed (7). Graham-Bryce also found this to be the case with disulfoton.

Herbicide movement within a soil is influenced considerably by soil moisture content. Herbicide movement to the adsorptive surfaces of plants is through either flow or diffusion (20). Reductions in soil moisture result in significant decreases in both processes. Scott and Paetzold (25) found the diffusion coefficient of metribuzin to decrease as moisture content decreased. Similar findings were reported for atrazine and propachlor (10, 24). It was concluded from these results that the principal effect of soil moisture on herbicide phytotoxicity is associated with herbicide transport.

Variations in soil moisture also can affect the rate of microbial breakdown of a number of herbicides. 3-amino-1,2,4-triazole is readily metabolized by soil microbes (6). With applications of the chemical to soils of 15 and 30% moistures, 8 and 0% of the applied herbicide was recovered after 6 days. However, when the herbicide was applied to air-dried soil, 58% was recovered after 6 days. Similar results were found for methazole (29).

Another major influence soil moisture has on the activity of a herbicide in soil is through the effect of moisture levels on chemical degradation. As previously mentioned, soil moisture can alter microbial activity, thereby increasing or decreasing microbial degradation, but soil moisture can also affect the rate of chemical degradation. Similar to all other soil moisture effects on herbicide activity, the amount of water and the herbicide involved determine whether or not the rate of chemical degradation will be altered.

Low soil moisture levels increase the amount of adsorption and put greater numbers of herbicide molecules in close contact with the colloidal surfaces. Hartley (17) has suggested that hydrolysis and oxidation reactors might be accelerated by adsorption of herbicides to soil colloids. Such reactions can also increase as a result of the location of the herbicides in the thin water film covering the soil colloids under low moisture conditions. The nature of the soil solution immediatley around the colloids is chemically and physically very different from the bulk solution. These altered characteristics, such as pH changes, can affect the rate herbicides degrade chemically.

Hargrove and Merkle (16) demonstrated a loss of alachlor by chemical degradation from soil of low moisture content. They used soils treated with alachlor and placed in desiccators at five different relative humidities. These treatments were repeated at 22, 38, and 46 C. The loss of alachlor was greatest at the lowest relative humidity and at the highest temperature. Alachlor loss decreased as R.H. increased to the point where volatility became a contributing factor. Hargrove and Merkle analyzed the soil for alachlor using gas chromatography and were able to show that the alachlor was actually degrading under conditions of low R.H. and high temperature. They attributed this loss to the increased acidity of the remaining water in a soil of low moisture content. The water molecules, as described by Mortland and Raman (22), are attracted by the electrostatic pull of the ions associated with the soil colloids, weakening their O-H bonds. This results in an increased polarization and ionization of the water molecules. The low water content and increased ionization significantly reduce the pH of aqueous medium surrounding the herbicides in solution. Similar chemical degradation in acid soil solutions has been noted for a number of s-triazine herbicides (3, 4, 26).

Appendix Table 1. Fresh weight and dry weight of corn with 48-h dry period.

	Fresh Weights (g)			Dry Weights (g)		
	Rate (kg/ha)			Rate (kg/ha)		
Soil Moisture Level	0.84	1.13	1.40	0.84	1.13	1.40
Dry						
R1	1850	1850	1650	394	455	374
R2	1825	1400	1700	324	254	363
R3	1875	1250	1600	371	240	300
R4	1550	1625	1775	318	377	357
R5	1775	1800	1575	349	358	340
$\bar{X}$	1775	1585	1656	351	337	347
Wet						
R1	1425	1575	1200	307	305	230
R2	1075	1500	1075	223	335	231
R3	1375	1225	1150	210	240	195
R4	1350	1625	1325	235	280	217
R5	1800	1500	1300	345	346	237
$\bar{X}$	1405	1485	1210	264	301	222

Control	R1	2000	R4	1913	R1	471	R4	391
	R2	1588	R5	1738	R2	339	R5	313
	R3	1613	$\bar{X}$	1770	R3	306	$\bar{X}$	364

Appendix Table 2. Visual evaluations and arcsine transformation for corn trial with 48-h dry period

	Visual Evaluation[1] Rate (kg/ha)			Arcsine Transformation Rate (kg/ha)		
Soil Moisture Level	0.84	1.13	1.40	0.84	1.13	1.40
Dry						
R1	70	60	50	56.8	50.8	45.0
R2	70	100	50	56.8	90.0	45.0
R3	90	80	70	71.6	63.4	56.8
R4	45	60	55	42.1	50.8	47.9
R5	90	50	50	56.8	45.0	45.0
$\overline{X}$	73	70	55	56.8	60.0	47.9
Wet						
R1	30	30	25	33.2	33.2	30.0
R2	25	25	45	30.0	30.0	42.1
R3	30	25	35	33.2	30.0	36.3
R4	55	35	25	42.1	36.3	30.0
R5	25	25	25	30.0	30.0	30.0
$\overline{X}$	33	28	31	33.7	31.9	33.7

[1]Visual Evaluation Scale: 0 = complete kill, 100 = no injury

Appendix Table 3. Analysis of variance for fresh weight of corn expressed as a percent of check (48-h dry period).

Source of Var.	df	SS	MS	F
Reps	4	882	221	2.23
Treatments	5	3329	666	6.73**
Soil Moisture	1	2336	2336	23.61**
Rate	2	398	188	2.01
SM x Rate	2	595	297	3.01
Error	20	1979	99	
Total	29	6189		

C.V. = 11.5%

Appendix Table 4. Analysis of variance for arcsine transformation of visual evaluations for corn trial with 48-h dry period.

Source of Var.	df	SS	MS	F
Reps	4	471	118	1.45
Treatments	5	3975	795	9.81**
Soil Moisture	1	3573	3573	44.01**
Rate	2	156	78	0.96
SM x Rate	2	246	123	1.51
Error	20	1624	81	
Total	29	6068		

C.V. = 20.5%

Appendix Table 5. Fresh weight and dry weight of corn with 72-h dry period.

	Fresh Weight (g)			Dry Weight (g)		
	Rate (kg/ha)			Rate (kg/ha)		
Soil Moisture Level	0.84	1.13	1.40	0.84	1.13	1.40
Dry						
R1	1400	1600	1550	339	370	244
R2	1200	1075	1550	181	180	328
R3	925	900	1275	137	163	215
R4	950	1075	1375	182	200	270
R5	1050	1425	825	226	264	169
$\bar{X}$	1105	1215	1315	213	235	245
Wet						
R1	875	925	1050	136	163	191
R2	1125	725	850	201	135	173
R3	1125	750	650	199	122	108
R4	875	975	750	171	180	116
R5	1250	850	900	286	181	135
$\bar{X}$	1050	845	840	199	156	145

Control	R1	1463	R4	1488	R1	250	R4	335
	R2	1350	R5	1200	R2	297	R5	195
	R3	1213	$\bar{X}$	1343	R3	233	$\bar{X}$	262

Appendix Table 6. Visual evaluations and arcsine transformations for corn trial with 42-h dry period.

Soil Moisture Level	Visual Evaluation[1] Rate (kg/ha)			Arcsine Transformation Rate (kg/ha)		
	0.84	1.13	1.40	0.84	1.13	1.40
Dry						
R1	100	50	60	90.0	45.0	50.8
R2	60	70	70	50.8	56.8	56.8
R3	90	50	35	71.6	45.0	36.3
R4	80	60	60	63.4	50.8	50.8
R5	90	70	50	71.6	56.8	45.0
$\overline{X}$	84	60	55	69.5	50.9	47.9
Wet						
R1	15	15	15	22.8	22.8	22.8
R2	26	20	35	30.0	26.6	36.3
R3	25	25	20	30.0	30.0	26.6
R4	35	20	15	36.3	26.6	22.8
R5	40	15	20	39.2	22.8	26.6
$\overline{X}$	28	19	21	31.7	25.8	27.0

[1]Visual Evaluation Scale: 0 = complete kill, 100 = no injury.

Appendix Table 7. Analysis of variance for fresh weight of corn expressed as a percent of check (72-h dry period).

Source of Var.	df	SS	MS	F
Reps	4	1470	367	1.61
Treatments	5	5050	1010	4.43**
Soil Moisture	1	3538	3538	15.55**
Rate	2	95	47	0.21
SM x Rate	2	1417	709	3.11
Error	20	4551	228	
Total	29	11,071		

C.V. = 19.0%

Appendix Table 8. Analysis of variance for arcsine transformation of visual evaluations for corn trial with 72-h dry period.

Source of Var.	df	SS	MS	F
Reps	4	48	12	0.16
Treatments	5	7321	1464	20.06**
Soil Moisture	1	5860	5860	79.86**
Rate	2	1074	537	7.32**
SM x Rate	2	387	194	2.64
Error	20	1468	73	
Total	29	8837		

C.V. = 20.3%

Appendix Table 9. Fresh weight of winter wheat with 48-h dry period.

	Fresh Weight (g)			
	Herbicide Rate (kg/ha)			
Soil Moisture Level	0.28	0.56	0.84	1.13
Dry				
R1	9720	9615	12010	8540
R2	12295	9660	11520	7205
R3	9645	9070	8440	8730
R4	13370	8660	11110	8440
R5	11840	10715	7480	9365
$\overline{X}$	11374	9544	10112	8456
Wet				
R1	12375	8760	3825	3645
R2	10760	9095	8660	7570
R3	11855	9895	8230	4450
R4	9455	12160	7080	5895
R5	12430	12865	6365	3020
$\overline{X}$	11375	10297	6279	5707

Control	R1	12453	R4	11700
	R2	12543	R5	12308
	R3	11975	$\overline{X}$	12196

Appendix Table 10. Dry weight of winter wheat with 48-h dry period.

	Dry Weight (g)			
	Herbicide Rate (kg/ha)			
Soil Moisture Level	0.28	0.56	0.84	1.13
Dry				
R1	2310	2325	2785	2060
R2	3070	2360	2750	1700
R3	2235	2155	1985	2345
R4	3340	2135	2915	2005
R5	2765	2540	1835	2270
$\bar{X}$	2744	2303	2454	2076
Wet				
R1	3120	2060	890	965
R2	2605	2240	2265	1915
R3	2885	2550	1820	1120
R4	2415	3060	1720	1360
R5	2300	2880	1625	650
$\bar{X}$	2665	2529	1483	1412

Control	R1	3168	R4	2915
	R2	2838	R5	3238
	R3	2883	$\bar{X}$	3008

Appendix Table 11. Visual evaluations and arsine transformations for winter wheat trial with 48-h dry period.

	Visual Evaluation[1]				Arcsine Transformation			
	Herbicide Rate (kg/ha)							
Soil Moisture Level	0.28	0.56	0.86	1.13	0.28	0.56	0.86	1.13
Dry								
R1	100	90	60	70	90.0	71.6	50.8	56.8
R2	90	70	90	40	71.6	56.8	71.6	39.2
R3	90	90	60	80	71.6	71.6	56.8	63.4
R4	90	80	80	70	71.6	63.4	63.4	56.8
R5	90	70	50	60	71.6	56.8	50.8	50.8
$\overline{X}$	92	80	68	64	75.3	64.0	58.7	53.4
Wet								
R1	90	70	20	30	71.6	56.8	26.6	33.2
R2	90	70	50	40	71.6	56.8	45.0	39.2
R3	90	100	70	40	71.6	90.0	50.8	39.2
R4	100	90	70	40	90.0	71.6	56.8	39.2
R5	90	80	60	20	71.6	63.4	45.0	26.6
$\overline{X}$	92	82	54	34	75.3	67.7	44.8	35.5

[1]Visual Evaluation Scale: 0 = complete kill, 100 = no injury.

Appendix Table 12. Analysis of variance for fresh weight of winter wheat expressed as a percent of check (48-h dry period).

Source of Var.	df	SS	MS	F
Reps	4	686	172	0.96
Treatments	7	12132	1733	9.68**
Soil Moisture	1	1374	1374	7.67**
Rate	3	8133	2711	15.14**
SM x Rate	3	2625	875	4.89**
Error	28	5013	179	
Total	39	17831		

C.V. 17.8%

Appendix Table 13. Analysis of variance of arcsin transformation of visual evaluations for winter wheat trial with a 48-h dry period.

Source of Var.	df	SS	MS	F
Reps	4	669	167	2.18
Treatments	7	7079	1011	13.13**
Soil Moisture	1	493	493	6.43*
Rate	3	5763	1921	25.06**
SM x Rate	3	823	274	3.578*
Error	28	2146	77	
Total	39	9894		

C.V. = 14.8%

Appendix Table 14. Fresh weight of winter wheat with 96-h dry period.

	Fresh Weight (g)			
	Herbicide Rate			
Soil Moisture Level	0.28	0.56	0.84	1.13
Dry				
R1	15055	12125	8910	8180
R2	12385	12235	11560	8760
R3	12780	11190	9550	7330
R4	11915	11130	8555	7740
R5	11520	12640	11220	9770
$\bar{X}$	12731	11864	9959	8356
Wet				
R1	12555	9990	4340	1710
R2	14375	9605	8540	2225
R3	11665	8265	8800	5475
R4	10670	10460	7955	3165
R5	10245	5480	2935	2935
$\bar{X}$	11902	8760	6514	3102

Control	R1	14658	R4	9943
	R2	11853	R5	12390
	R3	10918	$\bar{X}$	11952

Appendix Table 15. Dry weight of winter wheat with 96-h dry period

	Dry Weight (g)			
	Herbicide Rate			
Soil Moisture Level	0.28	0.56	0.84	1.13
Dry				
R1	3435	2655	2035	1900
R2	2915	2785	2795	2065
R3	2975	2550	2215	1940
R4	2745	2605	1935	1890
R5	2600	2755	2465	2305
$\overline{X}$	2934	2670	2289	2020
Wet				
R1	2885	2370	985	400
R2	3305	2265	1990	500
R3	2880	1960	2090	1390
R4	2725	2380	1870	785
R5	2345	1185	680	645
$\overline{X}$	2828	2032	1523	744

Control	R1	3490	R4	2448
	R2	2758	R5	2810
	R3	2625	$\overline{X}$	2826

Appendix Table 16. Visual evaluations and arcsine transformations for winter wheat trial with 96-h dry period.

	Visual Evaluation[1]				Arcsine Transformation			
	Herbicide Rate (kg/ha)							
Soil Moisture Level	0.28	0.56	0.84	1.13	0.28	0.56	0.84	1.13
Dry								
R1	90	90	80	70	71.6	71.6	63.4	56.8
R2	100	100	80	80	90.0	90.0	63.4	63.4
R3	100	90	90	90	90.0	71.6	71.6	56.8
R4	100	90	75	75	90.0	71.6	60.0	71.6
R5	90	100	80	80	71.6	90.0	63.4	50.8
$\overline{X}$	96	94	81	79	87.6	79.0	64.4	59.9
Wet								
R1	90	75	40	5	71.6	60.0	39.2	12.9
R2	100	90	70	10	90.0	71.6	56.8	18.4
R3	100	80	80	60	90.0	63.4	63.4	50.8
R4	70	90	70	15	56.8	71.6	56.8	22.8
R5	80	50	30	10	63.4	45.0	33.2	18.4
$\overline{X}$	88	77	58	20	74.4	62.3	49.9	24.7

[1]Visual Evaluation Scale: 0 = complete kill, 100 = no injury.

Appendix Table 17. Analysis of variance for fresh weight of winter wheat expressed as a percent of check (96-h dry period).

Source of Var.	df	SS	MS	F
Reps	4	5113	1278	8.46**
Treatments	7	25495	3642	24.12**
Soil Moisture	1	6378	6378	42.20**
Rate	3	17213	5737	37.96**
SM x Rate	3	1904	635	4.20*
Error	28	4232	151	
Total	39	34830		

C.V. = 15.7%

Appendix Table 18. Analysis of variance of arcsine transformation of visual evaluations for winter wheat trial with 96-h dry period.

Source of Var.	df	SS	MS	F
Reps	4	1512	378	4.06*
Treatments	7	12088	1727	18.57**
Soil Moisture	1	3480	3480	37.42**
Rate	3	7599	2533	27.23**
SM x Rate	3	1009	336	3.62*
Error	28	2604	93	
Total	39	16204		

C.V. = 15.5%

Appendix Table 19. Fresh weight of wheat treated preemergence with ethofumesate, using five soil moisture levels.

		Fresh Weight (mg)			
		Herbicide Rate (kg/ha)			
Soil Moisture Level		0	0.15	0.30	0.60
2%	R1	1458	1455	384	381
	R2	1852	1215	713	310
	R3	1576	756	527	230
	R4	1581	1884	1108	310
	$\overline{X}$	1617	1328	683	308
5%	R1	1751	668	141	141
	R2	1564	1029	252	103
	R3	820	414	313	242
	R4	2193	373	112	166
	$\overline{X}$	1582	621	205	163
9%	R1	1550	370	194	106
	R2	1610	263	219	105
	R3	1919	378	112	86
	R4	1807	377	310	184
	$\overline{X}$	1722	347	209	120
15%	R1	1473	643	97	164
	R2	1571	962	289	143
	R3	1675	1079	360	249
	R4	2227	911	386	123
	$\overline{X}$	1737	899	283	170
36%	R1	1167	156	96	58
	R2	2073	617	123	15
	R3	2304	470	20	56
	R4	2242	323	104	29
	$\overline{X}$	1947	392	86	40

Appendix Table 20. Dry weight of wheat treated preemergence with ethofumesate using five soil moisture levels.

Soil Moisture Level		Dry Weight (mg) Herbicide Rate (kg/ha) 0	0.15	0.30	0.60
2%	R1	144	152	57	53
	R2	179	133	81	51
	R3	144	78	62	34
	R4	141	199	125	49
	$\overline{X}$	152	141	81	47
5%	R1	163	71	20	16
	R2	159	120	37	17
	R3	67	44	42	38
	R4	197	44	16	25
	$\overline{X}$	147	70	29	24
9%	R1	145	48	25	13
	R2	156	34	31	21
	R3	181	46	11	12
	R4	156	49	43	33
	$\overline{X}$	160	44	28	20
15%	R1	138	66	7	25
	R2	153	114	42	26
	R3	152	111	52	33
	R4	208	102	51	24
	$\overline{X}$	163	98	38	27
36%	R1	115	12	12	10
	R2	218	78	20	6
	R3	224	50	5	20
	R4	239	42	27	7
	$\overline{X}$	199	46	16	11

Appendix Table 21. Visual evaluation of wheat treated pre-emergence with ethofumesate using five soil moisture levels.

Soil Moisture Level		Visual Evaluation[1] Herbicide Rate (kg/ha) 0.15	0.30	0.60
2%	R1	70	20	20
	R2	50	35	15
	R3	50	40	20
	R4	85	50	30
	$\overline{X}$	64	36	21
5%	R1	30	10	10
	R2	50	25	20
	R3	40	40	30
	R4	20	10	10
	$\overline{X}$	35	21	18
9%	R1	30	20	20
	R2	25	20	20
	R3	30	15	15
	R4	30	25	20
	$\overline{X}$	29	20	19
15%	R1	40	5	10
	R2	55	25	20
	R3	60	40	30
	R4	40	20	5
	$\overline{X}$	49	24	16
36%	R1	10	1	1
	R2	40	5	0
	R3	35	0	1
	R4	10	1	1
	$\overline{X}$	24	2	1

[1]Visual Evaluation Scale: 0 - complete kill, 100 = no injury.

Appendix Table 22. Analysis of variance of $\log_{10}$ transformations of fresh weight of wheat treated preemergence with ethofumesate, using five soil moisture levels.

Source of Var.	df	SS	MS	F
Reps	3	0.114	0.038	1.11
Treatments	19	19.826	1.043	30.69**
Soil Moisture	4	3.085	0.771	22.47**
Rate	3	15.018	5.006	145.90**
SM x Rate	12	1.723	0.144	4.19**
Error	57	1.956	0.034	
Total	79	21.895		

C.V. = 7.1%

Appendix Table 23. Fresh weight of wheat treated preemergence with ethofumesate using five soil moisture levels, preliminary study.

		Fresh Weight (mg)		
		(Herbicide Rate (kg/ha)		
Soil Moisture Level		0	0.15	0.60
2%	R1	1818	842	289
	R2	1248	1173	231
	R3	1563	1086	346
	$\overline{X}$	1543	1034	289
4%	R1	1940	430	198
	R2	1855	554	106
	R3	2001	774	153
	$\overline{X}$	1932	599	152
6%	R1	1596	651	166
	R2	1044	523	169
	R3	1967	513	182
	$\overline{X}$	1869	562	172
9%	R1	1735	420	239
	R2	1791	676	126
	R3	2243	522	156
	X	1923	539	174
35%	R1	2157	191	71
	R2	1828	203	18
	R3	1986	135	44
	X	1990	176	44

Appendix Table 24. Visual evaluations of wheat treated pre-emergence with ethofumesate, using five soil moisture levels, preliminary study.

Soil Moisture Level		Visual Evaluation[1] Herbicide Rate (kg/ha) 0.15	0.60
2%	R1	40	25
	R2	85	30
	R3	75	25
	$\overline{X}$	67	27
4%	R1	30	15
	R2	45	10
	R3	40	10
	$\overline{X}$	38	12
6%	R1	35	10
	R2	50	15
	R3	30	15
	$\overline{X}$	38	13
9%	R1	25	20
	R2	35	10
	R3	20	15
	$\overline{X}$	27	12
35%	R1	10	5
	R2	10	1
	R3	5	5
	$\overline{X}$	8	4

[1]Visual Evaluation Scale: 0 = complete kill, 100 = no injury.

Appendix Table 25. Fresh weight of corn treated preemergence with ethofumesate, using five moisture levels.

Soil Moisture Level		Fresh Weight (mg)			
		Herbicide Rate (kg/ha)			
		0	0.5	1.0	1.5
2%	R1	6744	4005	599	555
	R2	5992	2203	769	850
	R3	6120	2561	901	446
	R4	2730	1243	1014	395
	$\bar{X}$	5397	2503	821	562
4%	R1	4680	1786	730	706
	R2	5128	2759	734	661
	R3	6228	2078	816	537
	R4	5468	1391	731	637
	$\bar{X}$	5376	2004	753	536
8%	R1	4025	800	594	330
	R2	4664	1363	686	632
	R3	5918	997	545	484
	R4	4441	1510	514	402
	$\bar{X}$	4762	1168	585	462
14%	R1	4533	1829	779	200
	R2	5083	1801	690	269
	R3	5043	3102	735	482
	R4	3524	1206	608	536
	$\bar{X}$	4546	1985	703	372
25%	R1	4693	1099	1334	296
	R2	5244	1370	632	495
	R3	5101	684	1029	816
	R4	3521	1026	336	721
	$\bar{X}$	4640	1047	833	582

Appendix Table 26. Visual evaluation of corn treated pre-emergence with ethofumesate, using five moisture levels.

Soil Moisture Level	Herbicide Rate (kg/ha)	Visual Evaluation[1] R1	R2	R3	R4	$\overline{X}$
2%	0.5	70	50	50	60	58
	1.0	15	15	25	40	24
	1.5	10	25	10	20	16
4%	0.5	40	45	40	30	39
	1.0	25	20	20	20	21
	1.5	20	15	15	10	15
8%	0.5	30	30	25	40	31
	1.0	25	25	10	10	18
	1.5	10	15	10	10	11
14%	0.5	45	45	60	40	48
	1.0	25	20	25	25	24
	1.5	10	10	10	25	14
25%	0.5	25	30	15	30	25
	1.0	30	15	25	10	20
	1.5	10	10	20	15	14

[1]Visual Evaluation Scale: 0 = complete kill, 100 = no injury.

Appendix Table 27. Fresh weight of wheat treated with ethofumesate incorporated 2 cm.

Irrigation Days After Application		Fresh Weight (mg)					
		Soil Moisture Level					
		2%			12%		
		Herbicide Rate (kg/ha)					
		0	0.2	0.4	0	0.2	0.4
0	R1	6798	25	12	5953	89	18
	R2	4560	53	24	6538	743	12
	R3	7637	331	23	6733	1324	30
	R4	7492	13	47	6680	600	58
	$\overline{X}$	6622	106	27	6476	689	30
2	R1	5443	2991	584	5931	51	10
	R2	5342	3091	1112	4806	311	20
	R3	5494	2434	925	4998	35	15
	R4	5536	2313	973	5984	80	22
	$\overline{X}$	5454	2707	899	5430	119	17
4	R1	5227	1466	245	7098	96	42
	R2	6874	1847	1009	6146	29	16
	R3	6286	2160	370	6415	158	29
	R4	6335	2002	27	7414	57	28
	$\overline{X}$	6180	1869	413	6768	85	29

Appendix Table 28. Dry weight of wheat treated with ethofumesate incorporated 2 cm.

		Dry Weight (mg)					
		Soil Moisture Level					
		2%			12%		
		Herbicide Rate (kg/ha)					
Application		0	0.2	0.4	0	0.2	0.4
0	R1	1261	16	4	1077	21	11
	R2	867	14	13	1281	104	3
	R3	1338	51	10	1213	186	15
	R4	1424	7	14	1328	76	21
	$\bar{X}$	1223	22	10	1225	97	13
2	R1	971	394	66	1012	14	6
	R2	954	450	129	853	53	5
	R3	926	303	109	786	12	8
	R4	1015	312	117	1105	22	6
	$\bar{X}$	967	365	105	939	25	6
4	R1	766	168	33	1164	25	16
	R2	1228	223	116	947	9	8
	R3	990	266	40	966	27	10
	R4	1021	260	6	1224	21	11
	$\bar{X}$	1001	229	49	1075	21	11

Appendix Table 29. Visual evaluation of wheat injury treated with ethofumesate incorporated 2 cm.

Irrigation Days After Application		Visual Evaluations[1] Soil Moisture Level 2% Herbicide Rate (kg/ha) 0.2	2% 0.4	12% 0.2	12% 0.4
0	R1	1	1	5	1
	R2	1	1	20	1
	R3	10	1	25	1
	R4	1	5	20	1
	$\overline{X}$	3	2	18	1
2	R1	60	15	5	1
	R2	60	25	5	1
	R3	60	20	1	1
	R4	50	25	1	1
	$\overline{X}$	58	21	3	1
4	R1	30	10	5	1
	R2	40	25	1	1
	R3	40	15	5	1
	R4	40	1	1	1
	$\overline{X}$	38	13	3	1

[1]Visual Evaluation Scale: 0 = complete kill, 100 = no injury.

Appendix Table 30. Analysis of variance of fresh weight of wheat, expressed as percent of respective check, treated with ethofumesate incorporated 2 cm.

Source of Var.	df	SS	MS	F
Reps	3	87	29	1.90
Treatments	11	7809	710	47.33**
Soil Moisture	1	2672	2672	175.46**
Rate	1	1682	1682	110.44**
Time	2	1579	789	51.85**
SM x Rate	1	686	686	45.07**
Rate x Time	2	295	147	9.68**
SM x Rate x Time	2	895	447	29.39**
Error	33	502	15	
Total	47	11062		

C.V. = 39.0%

Appendix Table 31. Fresh weight of wheat treated with ethofumesate incorporated 2 cm, preliminary study.

Irrigation Days After Application		Fresh Weight (mg) Soil Moisture Level 2% Herbicide Rate (kg/ha) 0	2% 0.2	2% 0.4	12% 0	12% 0.2	12% 0.4
0	R1	5235	177	43	5091	832	31
	R2	4826	112	72	5142	778	87
	R3	4992	211	69	4744	342	79
	$\overline{X}$	5018	167	61	4992	651	66
2	R1	4879	2892	1009	4586	431	56
	R2	4402	2405	1087	4662	106	17
	R3	4633	2577	1263	4555	132	82
	$\overline{X}$	4638	2625	1120	4601	223	52
4	R1	4955	2044	837	5189	87	57
	R2	5013	1791	695	4877	165	63
	R3	5321	1911	712	5216	152	95
	$\overline{X}$	5096	1915	748	5094	135	72

Appendix Table 32. Visual evaluations of wheat treated with ethofumesate incorporated 2 cm, preliminary study.

Irrigation Days After Application		Visual Evaluation[1] Soil Moisture Level 2% Herbicide Rate (kg/ha) 0.2	2% 0.4	12% 0.2	12% 0.4
0	R1	10	5	20	5
	R2	10	10	25	10
	R3	15	5	20	10
	$\bar{X}$	12	7	22	8
2	R1	70	35	20	5
	R2	50	35	10	1
	R3	50	40	15	10
	$\bar{X}$	57	37	15	5
4	R1	50	20	5	5
	R2	40	20	15	5
	R3	40	20	15	10
	$\bar{X}$	43	20	12	7

[1]Visual Evaluation Scale: 0 = complete kill, 100 = no injury.

Appendix Table 33. Gas chromatography study, μg of ethofumesate extracted per 50 g soil sample.

Days After Application	Soil Moisture Level	μg Extracted			
		R1	R2	R3	$\bar{X}$
0	Dry	390	330	330	350
	Wet	360	400	376	379
2	Dry	158	158	148	155
	Wet	384	413	360	386
4	Dry	87	97	122	102
	Wet	360	335	335	343
6	Dry	50	75	61	62
	Wet	365	370	417	384
12	Dry	40	30	35	35
	Wet	420	395	380	398

Appendix Table 34. Analysis of variance for Log_{10} transformations of μg of ethofumesate extracted per soil sample.

Source of Var.	df	SS	MS	F
Reps	2	0.067	0.033	1.00
Treatments	9	5.199	0.578	17.31**
Time	4	1.533	0.383	11.50**
Soil Moisture	1	2.133	0.133	64.00**
Time x SM	4	1.533	0.383	11.50**
Error	18	0.601	0.033	
Total	29	5.867		

Appendix Table 35. Gas chromatography preliminary study, μg of ethofumesate extracted per 50 g soil sample.

Days After Application	Soil Moisture Level	μg Extracted			
		R1	R2	R3	$\bar{X}$
0	Dry	287	338	625	416
	Wet	512	687	298	499
2	Dry	210	250	254	238
	Wet	271	313	310	298
4	Dry	147	140	218	168
	Wet	284	352	338	325
6	Dry	68	72	68	69
	Wet	313	348	304	322
12	Dry	15	5	15	12
	Wet	310	394	338	347

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