This is to certify that the

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Effect of Soil Applied Herbicides on
Corn Growth

presented by

Paul Edward Horny

has been accepted towards fulfillment
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Master ~~of Science~~degree in ~~Crop and~~ Soil Science

William F. Meggitt

Major professor

William F. Meggitt

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EFFECT OF SOIL APPLIED HERBICIDES ON CORN GROWTH

By

Paul Edward Horny

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ABSTRACT

EFFECT OF SOIL APPLIED HERBICIDES ON CORN GROWTH

By

Paul Edward Horny

The effect of alachlor (2-chloro-2',6'-diethyl-N-(methoxymethyl)acetanilide, metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide), acetochlor (2-chloro-N(ethoxymethyl)-6'-ethyl-o-acetotoluidide), butylate + R-25788 (S-ethyl diisobutylthiocarbamate + N,N-dially-2,2 dichloro acetamide), EPTC + R-25788 (S-ethyl dipropylthiocarbamate + N,N-dially-2,2 dichloroacetamide), and pendimethalin (N-(1-ethylpropyl)-3,4-dimethyl-2,6 dinitrobenzenamine) on corn (Zea mays) germination, root and shoot fresh and dry weights, plant water stress, potassium and phosphorus content, and yield was studied in 1982 and 1983. Herbicides were applied at normal use (1X), increasing rates (2X, 4X) except EPTC + R-25788 and pendimethalin, and applied preplant incorporated and preemergence with the acetanilides. Most differences in root and shoot weights occurred 4-5 weeks after planting. Acetochlor incorporated caused the greatest reductions in all parameters studied. EPTC + R-25788 caused reductions in root and shoot weights when compared to alachlor, metolachlor, butylate + R-25788 and pendimethalin. Alachlor incorporated showed a significant increase in the phosphorus content over that of plants treated with pendimethalin and preemergence alachlor, but all three were within corn sufficiency ranges.

Though differences were observed with alachlor, metolachlor, butylate + R-25788, EPTC + R-25788, and pendimethalin at all rates and methods of application, none significantly reduced yield.

To Anita, Paul Jr. and Anna for
their persistance.

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INTRODUCTION

Several effective grass control herbicides are registered for use in corn (Figure 1). Included are alachlor[1] (2-chloro-2',6'-diethyl-N-(methoxymethyl)acet anililde), metolachlor[2] (2-chloro-N-(2-ethyl-6-methyl phenyl)-N-(2-methoxy-1-methylethyl)acetamide), acetochlor[3] (2-chloro-N(ethoxymethyl)-6'-ethyl-o-acetotoluidide), butylate + R-25788[4] (S-ethyl diisobutylthiocarbamate + N,N-dially-2,2-dichloroacetamide), EPTC + R-25788[5] (S-ethyl dipropylthiocarbamate + N,N-dially-2,2-dichloroacetamide), and pendimethalin[6] (N-(1-ethylpropyl)-3,4 dimethyl-2,6 dinitrobenzenamine). Corn is tolerant to these herbicides under conditions of normal use, however data are being generated concerning comparative growth inhibition, corn injury, and stress from these materials. This causes concern over the use by growers who use these herbicides as a basis for grass control in their weed control programs. It is important to generate data that will establish the safety of these herbicides in comparison with each other and to an untreated control under normal field conditions.

The purpose of this study was to: (1) evaluate the effect on corn growth from the different soil applied herbicides; (2) evaluate the effect on corn growth with

increasing rates of herbicides; (3) evaluate the effect on corn growth with different application methods.

[1]Registered as Lasso[R] by Monsanto Company.

[2]Registered as Dual[R] by Ciba-Geigy Corporation.

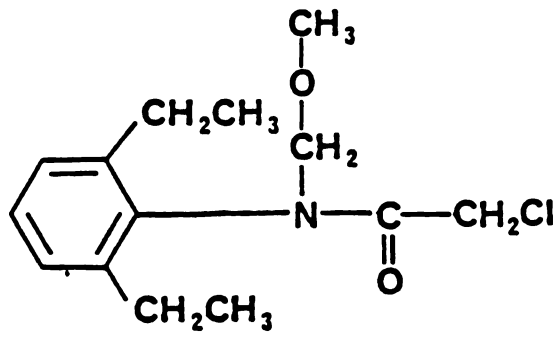
[3]Registered as Harness[R] by Monsanto Company.

[4]Registered as Sutan+[R] by Stauffer Chemical Company.

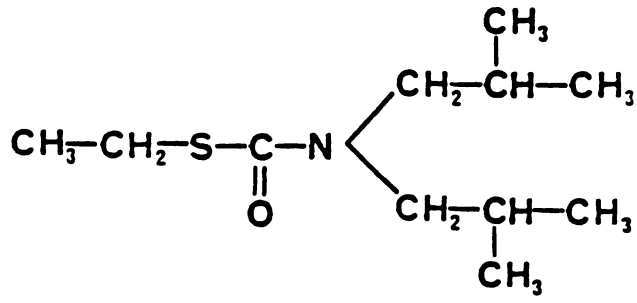
[5]Registered as Eradicane[R] by Stauffer Chemical Company.

[6]Registered as Prowl[R] by American Cyanimid.

Figure 1. Chemical structures of alachlor, metolachlor, acetochlor, butylate, R-25788, EPTC, and pendimethalin.



alachlor



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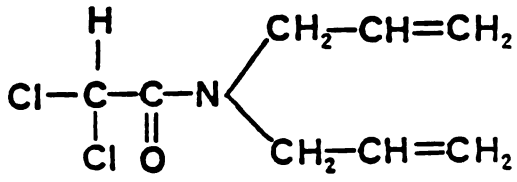
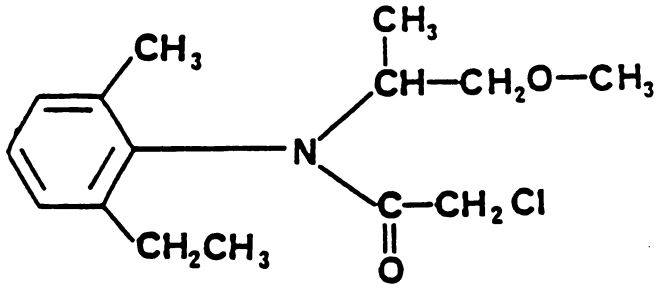


R-25788



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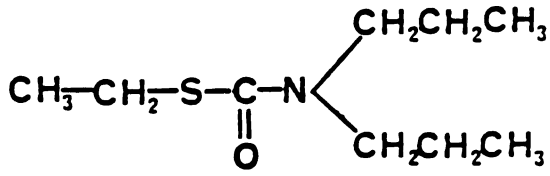

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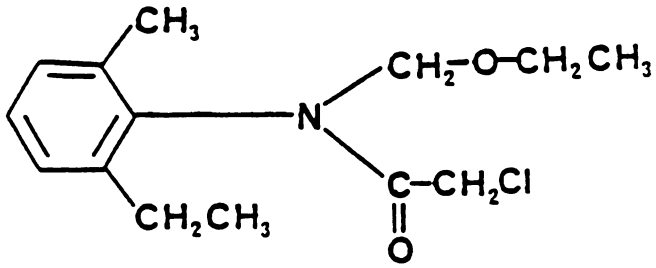
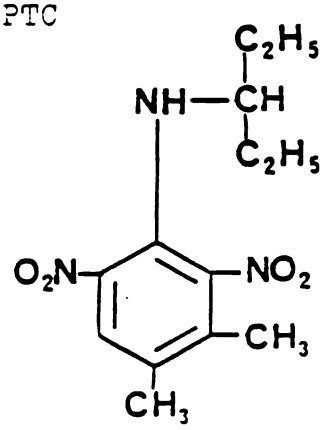


acetochlor



pendimethalin

REVIEW OF THE LITERATURE

Plant Population

Reduced germination of corn has been reported for alachlor (19), metolachlor (26,35,58), butylate+R-25788 and EPTC+R-25788 (49,50,70). All reduced stands with normal and increased rates of herbicides. The reductions in plant population did not result in changes in root development (74), water use and yield (55,69). Acetochlor caused the greatest reduction in germination (38), Lee and Alley (42) reported a 37% reduction in the corn stand.

Root and Shoot Fresh and Dry Weights

Root and shoot growth of corn at early growth stages is affected by all soil applied herbicides. Alachlor (22, 28,37,40,45), metolachlor (21,22,26,40) and acetochlor (40,68) reduce root and shoot growth early in the growing season. Increased rates of these herbicides produced corresponding reductions in corn growth (21,27,28). Differences between incorporated and preemergence treatments varied over different conditions (32,44).

Butylate+R-25788 and EPTC+R-25788 both caused reductions in the growth of corn. Although both of these herbicides without the added safener cause injury to corn, and with the addition of R-25788 corn injury is reduced

substantially (2,66,67), they both have been reported to inhibit corn growth with the addition of the safener R-25788 (11,12,13,16). Buzio and Burt (14) observed that EPTC and R-25788 separated in the soil columns and cited this as a possible reason for injury from this herbicide (12,13). They also reported that corn was most sensitive to EPTC+R-25788 injury four weeks after planting.

Pendimethalin applied preemergence caused reductions in corn root growth (43), especially after incorporation of the herbicide by rainfall (18,64), or by placing the corn seed at shallow planting depths (57). Pendimethalin incorporated does cause the most injury to corn (43), but is not recommended as a herbicide treatment for corn.

Plant Water Stress

The growth stage of corn that is most directly affected by water stress is pollination (34). Robins and Domingo (62) reported up to a 50% reduction in yield when the plants were under water stress during pollination. Denmead and Shaw (23) observed the same yield reduction from water stress at pollination but also found that water stress early in the growing season had an indirect effect on yield by reducing the amount of photoassimilates available for ear filling.

Measuring plant water stress is difficult under field conditions due to the many factors involved (1,20,47,60, 65), therefore absolute values cannot be obtained. Instead, relative values (8) are measured under steady

state conditions which lend themselves to analysis by multiple comparisons.

Alachlor has been shown to increase transpiration of corn (3), oats (46), and potatoes (13), but the plants were not under severe water stress under normal field conditions. EPTC caused increased water loss in corn (9,41), but with addition of R-25788 the formation of epicuticular wax was not changed (31,41), and transpiration is not increased.

Corn Leaf Nutrient Content

Rehm et. al., (61) found that phosphorus uptake was closely associated with relative yield. Alachlor at higher concentrations increased the phosphorus content of corn plant shoots (59). Alachlor and trifluralin[9] (α,α,α-trifluoro-2,6-dinitro-N-N-dipropyl-p-toluidine) decreased phosphorus uptake (10) due to reduction of the total corn root mass (6). Reductions in phosphorus accumulation in corn caused by metolachlor have been observed by Ellis and Wilson (29). Balke (5) reported that both metolachlor and alachlor inhibited potassium absorption in oat roots. EPTC decreased the phosphorus content (6) in french bean seeds (Phaseolus vugaris var.), while alachlor increased the total phosphorus content in seeds of peanut (Arachis hypogaea).

[9]Registered as Treflan[R] by Elanco Co.

Corn Grain Yield

Alachlor (17, 75), metolachlor (24, 75), acetochlor (17), butylate+R-25788 and EPTC+R-25788 (52,75), and pendimethalin (43,57) at normal use rates have no effect on corn yield. Where yield differences were found plots were not hand weeded so the effect of the herbicide treatments on yield could be compared, not the effect of increased or decreased weed pressure. Weeds left growing have a deliterious effect on crop yield (48). Increasing rates of alachlor and metolachlor did not reduce yields (24). Incorporated acetochlor and alachlor did not show any difference in yield over preemergence treatments at the same rate (17).

Varietal Differences

Differences in corn varietal response to soil applied herbicides have been observed with alachlor (30,53,75), metolachlor (75), and acetochlor (7). More injury occurred with inbred lines than the hybrids, and injury was seen more often early in the season. Tolerance of different varieties to butylate+R-25788 (16,56,73,75) and EPTC+R-25788 (15,39,63,72,75) also showed most injury early in the growing season, greater injury was seen with the inbreds than the hybrids. Niccum (54) reported that alachlor and butylate were safe to use on commercial varieties but should not be used with the inbreds without knowledge of the possible consequences. Zawierucha and Hartwig (75) observed that injury and stunting in the early season

from the differences in the varieties was not enough to cause a significant impact on yield.

MATERIALS AND METHODS

General Information

The treatments for this experiment are as listed (Figure 2). On May 5, 1982 and May 17, 1983 the preplant incorporated treatments were sprayed, then one pass incorporated with an implement with danish S-tynes and rolling baskets, three inches deep. The preemergence treatments were sprayed on the same day. The preemergence and the control had one pass tillage prior to treatment for uniform seedbed preparation. The corn was planted on May 5 north to south and May 17 east to west with a four row planter. The plots were four rows, 3.04m by 18.24m long, with four different varieties per plot: Voris 2381, Great Lakes 422, Voris 2331, and Pioneer 3901. There were four replications of the treatments each year. All plots were hand weeded to eliminate weed competition. Before planting 505 kg/ha of urea (45-0-0) was incorporated in each year. Two hundred twenty three kg per hectare of 19-19-19 in 1982 and 223 kg/ha of 5-20-20 in 1983 was band applied with the planter. The soil was a loam texture, pH 6.5, with 3.3% organic matter. The soil temperature at planting time was 15.5C in 1982 and 12.7C in 1983.

Insecticide was not applied at planting in 1982 to avoid any possible interactions with the herbicides, but

Treatment (kg/ha)	1X	2X	4X
Alachlor, preplant incorporated	2.8	5.6	11.2
Alachlor, preemergence	2.2	4.4	8.8
Metolachlor, preplant incorporated	2.8	5.6	11.2
Metolachlor, preemergence	2.2	4.4	8.8
Acetochlor, preplant incorporated	2.2	4.4	8.8
Acetochlor, preemergence	1.7	3.4	6.8
Butylate+R-25788, preplant incorporated	3.4	6.8	13.6
EPTC+R-25788, preplant incorporated	6.8		
Pendimethalin, preemergence	1.7		
Untreated (hand weeded)			

Figure 2. List of herbicide treatments.

rootworms were a problem in the experiment during 1982. Rootworm larvae damage was seen throughout the experiment but was worse in treatments with lower plant populations. The plots were sprayed at silking with carbaryl[7] (1-naphthyl N-methylcarbamate) and crop oil to prevent the adult rootworms from damaging the silks. Rootworm insecticide, (0-ethyl S phenyl ethylphosphonodithioate)[8] was band applied above the row in 1983.

The split plot experimental design was employed both years. Data was analyzed with the Duncan's multiple range test at the five percent level. In each measurement, the average of the four varieties in each treatment is presented in the tables, except where noted.

Plant Population Measurements

On May 17, 1982 and May 31, 1983 the number of plants in 3.04m of row was counted for each of the four different varieties in every treatment.

Root and Shoot Fresh and Dry Weight Determinations

On May 19, 1982 and June 2, 1983, at the two leaf stage, five plants were dug from the north and east end of the plot. The plants were placed in plastic bags and sealed to reduce moisture loss. The five plants were

[7]Registered as Sevin® by Union Carbide Agricultural Products Company Incorporated.

[8]Registered as Dyfonate® by Stauffer Chemical Company.

washed and seedcoats were removed. The five plants were then blotted dry with a paper towel, separated at the root-shoot axis, roots and shoots weighed separately, oven dried, and weighed separately again. Plants were also harvested using the same process on May 26, 1982 and June 9, 1983, the three leaf stage, at the north and east end of the plot, June 2 and June 10, 1982 at the four leaf stage, and June 16 and June 23, 1983, the five leaf stage, at the south and west end of the plot. Plants were not removed from the acetochlor incorporated 2X and 4X treatments during 1982 so the few plants that remained could be used for further measurements.

The comparisons of root and shoot dry weights closely paralleled the comparisons of the fresh weights. Root and shoot dry weights will not be included in the text of this paper, but are included in the appendices (1-8).

Diffusive Resistance Measurements

A porometer was used to measure stomatal diffusive resistance (seconds per centimeter) as an indicator of plant water stress. It is assumed that stomates will close under water stress thus causing a higher resistance value, or the diffusive resistance is inversely proportional to the stomatal aperature under steady state conditions. A LI-COR^{R} LI-1600 steady state porometer was used for the measurements. After first setting the aperature (2.0cm), and the pressure for the altitude (98.5 kPa), the diffusive resistance can be measured. Only one variety was

measured (Pioneer 3901) in the interest of time so measurements could be taken between 10 a.m. and 2 p.m., the time of highest light intensity and stress during the day. One plant was chosen in the Pioneer 3901 row for each treatment and was used for measurements on May 11, June 22 and June 23, 1982 and June 14, 1983. The newest emerged leaf (having a visible collar) was used for the porometer measurements. Quantum readings, which measures the amount of photosynthetically active radiation (microeinsteins per square meter per second) were taken before each replication. The diffusive resistance readings were taken in direct sunlight.

Leaf Water Potential Measurements

On June 22 and June 23, 1982 at the six leaf stage the pressure bomb was used along with the porometer. The pressure bomb was used to measure leaf water potential (bars) of a leaf in the same row as the plant used for the porometer measurements. No measurements were taken in 1983. It was not possible to use the same plant as the porometer measurements because the newest leaf (having a visible collar) was removed for the water potential measurement. The leaf was placed in a plastic bag to reduce moisture loss then cut to approximately 15cm from the tip of the leaf so the leaves would be uniform. The proximal end of the leaf had sections removed from both sides of the midrib, leaving an area approximately 3cm long and 1cm on both sides of the midrib so the leaf would

fit in the narrow latex grommet used to hold the leaf in place in the cylinder cover on the pressure bomb. The cylinder was then pressurized with nitrogen gas. When sap was expressed, the corresponding pressure (converted to bars) was recorded.

Corn Leaf Nutrient Analysis

The ear leaf was removed from two Voris 2331 plants in each treatment at silking. This variety was chosen because of the higher average population across treatments. The leaves were rinsed in nondistilled water and rinsed again in two successive containers of distilled water to remove any dirt or chemicals on the leaf surface. The distilled water was changed periodically. The leaf samples were dried, and then ground to a 20 mesh particle size. Potassium and phosphorus was determined by plasma emission spectroscopy. The sample preparation procedure is listed in Appendix 14.

Corn Grain Yield

Corn was harvested on October 17, 1982 and October 25, 1983 with a one row research corn harvester. The amount of corn in 7.6m of row was weighed. A sample for moisture determinations was taken from each row in each treatment and sealed in a wax lined paper bag to reduce moisture loss. The yield data was then computed to kg/ha of corn at 15.5 percent moisture.

RESULTS AND DISCUSSION

Plant Population

None of the herbicide treatments at the normal use rates (1X) reduced corn plant population as compared to the control. Incorporated acetochlor at the 2X rate in 1982 and the 4X rate both years significantly reduced the corn stand (Table 1).

Incorporated acetochlor at the 4X rate both years and the 2X rate in 1982 significantly reduced stand compared to preemergence treatment at the same rate. Alachlor incorporated at the 2X rate in 1982 significantly reduced stand compared to the preemergence treatment at the same rate (Table 1), however, the 4X rate did not show the same pattern.

Root Fresh Weight

At the 1X rates, no treatments were significantly different than the control harvest 1 (two leaf stage) in 1982, and harvest 1, 2 and 4 during 1983 (Table 2, 3, and 5). Acetochlor incorporated (1X) caused the most consistant reductions in corn root weights at harvest 2 and 3 (three and four leaf stage) in 1982, and harvest 3 during 1983 (Table 3-4). All of the 1X herbicide treatments except butylate+R-25788 and alachlor preemergence

Table 1. The Effect of Soil Applied Herbicides at Three Rates on Corn Plant Population.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	plants/3.04m					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	7.6 a	9.6 ab	4.9 bc	9.9 a	8.9 a	9.5 a
Alachlor, PRE	7.5 a	9.3 b	9.1 a	10.0 a	9.4 a	9.0 a
Metolachlor, PPI	6.7 a	10.4 ab	7.1 ab	9.7 a	6.9 ab	9.7 a
Metolachlor, PRE	8.8 a	9.3 ab	8.6 a	10.3 a	9.1 a	10.6 a
Acetochlor, PPI	7.2 a	9.7 ab	3.2 c	8.8 a	4.0 b	7.4 b
Acetochlor, PRE	8.4 a	10.0 ab	8.7 a	8.8 a	8.0 a	8.9 a
Butylate+R-25788, PPI	6.6 a	9.7 ab	8.3 a	9.9 a	6.6 ab	9.4 a
EPTC+R-25788, PPI	7.8 a	9.9 ab	-	-	-	-
Pendimethalin, PRE	8.1 a	11.0 a	-	-	-	-
Untreated	8.1 a	10.0 ab	8.1 ab	10.0 a	8.1 a	10.0 a

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

reduced root growth at the third harvest during 1982. At the third harvest in 1983, EPTC+R-25788, butylate+ R-25788, acetochlor incorporated and preemergence reduced corn root fresh weights (Table 4). However, at the fourth harvest, the five leaf stage, in 1982 (Table 5) only EPTC+R-25788 and metolachlor preemergence treatments reduced corn root weights. Root weights of plants treated with acetochlor preemergence harvest 1, acetochlor incorporated and metolachlor preemergence harvest 2 were significantly less than plants treated with butylate+ R-25788 treatment at the 1X rate during 1983 (Table 2-3).

Alachlor incorporated at higher rates reduced corn root fresh weights at harvest 2 during 1982 and harvest 3 and 4 both years. Preemergence alachlor at higher rates caused reductions in root weights the third harvest both years and harvest 4 in 1982 (Table 3-5).

Higher rates of metolachlor resulted in decreased corn root weights at the second and fourth harvests during 1982 and the third harvest both years. The 4X rate of metolachlor especially when incorporated reduced root weights three of the four harvests in 1982 (Table 3-5).

Acetochlor incorporated at higher rates reduced root weights all four harvests in 1982 and harvests 2, 3 and 4 during 1983. Preemergence acetochlor also reduced corn root weights harvest 2 during 1983 and harvest 3 and 4 both years (Table 2-5).

Butylate+R-25788 caused root growth reductions only

Table 2. The Effect of Soil Applied Herbicides at Three Rates on Corn Root Fresh Weights, Two Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm fresh wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	4.3 a	1.6 ab	4.6 a	1.7 a	3.7 bc	1.6 a
Alachlor, PRE	4.8 a	1.8 ab	4.6 a	1.7 a	4.4 ab	1.9 a
Metolachlor, PPI	4.3 a	1.8 ab	3.9 a	1.7 a	4.1 abc	1.5 a
Metolachlor, PRE	4.6 a	1.9 ab	4.6 a	2.0 a	4.5 ab	1.6 a
Acetochlor, PPI	4.2 a	1.5 ab	-	1.8 a	3.6 c	1.6 a
Acetochlor, PRE	4.5 a	1.4 b	4.4 a	1.7 a	4.4 ab	1.6 a
Butylate+R-25788, PPI	4.7 a	2.0 a	4.2 a	1.8 a	4.9 a	1.7 a
EPTC+R-25788, PPI	4.5 a	1.8 ab	-	-	-	-
Pendimethalin, PRE	4.7 a	1.7 ab	-	-	-	-
Untreated	4.5 a	1.9 ab	4.5 a	1.9 a	4.5 a	1.9 a

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Table 3. The Effect of Soil Applied Herbicides at Three Rates on Corn Root Fresh Weights, Three Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm fresh wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	7.4 ab	2.9 abc	5.8 c	2.7 ab	6.3 ab	2.4 abcde
Alachlor, PRE	7.5 ab	2.5 abc	8.5 a	3.0 a	7.3 a	2.0 de
Metolachlor, PPI	6.7 ab	3.0 ab	6.5 bc	2.9 a	5.5 b	2.5 abcde
Metolachlor, PRE	8.1 a	2.2 c	7.2 abc	2.6 ab	7.6 a	2.3 bcde
Acetochlor, PPI	5.9 b	2.4 bc	-	2.5 ab	3.3 c	2.2 cde
Acetochlor, PRE	8.1 a	2.6 abc	7.5 abc	2.2 b	7.3 a	1.8 e
Butylate+R-25788, PPI	7.4 ab	3.3 a	7.7 ab	2.7 ab	7.9 a	3.1 a
EPTC+R-25788, PPI	7.8 a	2.7 abc	-	-	-	-
Pendimethalin, PRE	8.3 a	2.8 abc	-	-	-	-
Untreated	7.8 a	2.7 abc	7.8 ab	2.7 ab	7.8 a	2.7 abcd

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Table 4. The Effect of Soil Applied Herbicides at Three Rates on Corn Root Fresh Weights, Four Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm fresh wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	12.6 b	7.7 abc	11.2 bcd	6.6 bc	11.5 b	5.7 de
Alachlor, PRE	13.5 ab	7.3 abc	11.4 bcd	7.7 abc	13.1 b	6.4 bcd
Metolachlor, PPI	12.9 b	7.5 abc	9.4 cd	6.7 bc	12.2 b	7.0 bcd
Metolachlor, PRE	12.8 b	7.5 abc	11.7 bcd	7.2 bc	14.1 ab	6.9 bcd
Acetochlor, PPI	11.7 b	6.2 c	8.6 d	4.3 d	7.0 c	3.7 f
Acetochlor, PRE	12.9 b	7.2 bc	12.8 bc	6.1 c	11.5 b	4.2 ef
Butylate+R-25788, PPI	14.2 ab	7.1 bc	13.0 bc	6.4 bc	13.2 b	6.2 cd
EPTC+R-25788, PPI	12.6 b	6.9 bc	-	-	-	-
Pendimethalin, PRE	13.0 b	8.1 ab	-	-	-	-
Untreated	16.5 a	9.0 a	16.5 a	9.0 a	16.5 a	9.0 a

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Table 5. The Effect of Soil Applied Herbicides at Three Rates on Corn Root Fresh Weights, Five Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm fresh wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	25.4 ab	22.9 a	22.4 b	21.2 ab	22.5 b	15.3 bc
Alachlor, PRE	28.1 ab	22.6 a	24.1 b	22.9 ab	26.8 ab	18.5 ab
Metolachlor, PPI	28.2 ab	21.3 a	27.3 ab	18.0 abc	20.8 b	18.0 ab
Metolachlor, PRE	24.1 b	21.8 a	26.8 ab	17.0 abc	25.4 ab	19.4 ab
Acetochlor, PPI	24.9 ab	17.3 a	-	12.6 c	-	9.9 c
Acetochlor, PRE	24.2 ab	18.5 a	26.8 ab	15.6 bc	21.1 b	10.0 c
Butylate+R-25788, PPI	26.3 ab	20.5 a	23.2 b	18.5 abc	27.4 ab	19.9 ab
EPTC+R-25788, PPI	20.2 b	21.7 a	-	-	-	-
Pendimethalin, PRE	29.6 ab	22.3 a	-	-	-	-
Untreated	32.8 a	24.4 a	32.8 a	24.4 a	32.8 a	24.4 a

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

at the 2X and 4X rates the third harvest both years and harvest 4 in 1982 (Table 3-5).

More of the incorporated treatments in 1982 were significantly different from the control than the preemergence treatments at the same rate than in 1983. Only one incorporated treatment, acetochlor at the 4X rate, was less than the preemergence treatment at the same rate in 1983. Acetochlor showed the most differences between incorporated and preemergence at all rates, with differences between application methods observed also with alachlor at the 2X rate and metolachlor at the 4X rate both in 1982 (Table 2-4).

Shoot Fresh Weight

None of the herbicide treatments at normal use rates (1X) produced significantly lower shoot fresh weights than the control during both years. However, EPTC+R-25788 caused reductions in shoot fresh weights in one instance both years (Table 7 and 9) as compared to other treatments at the same harvest. Acetochlor incorporated and preemergence was also reduced as compared to other treatments at the same harvest at the 1X rate (Table 6-7).

Higher rates of alachlor, metolachlor or butylate+ R-25788 did not reduce shoot fresh weights, except alachlor the second harvest at the 4X rate (Table 7). Acetochlor caused shoot fresh weight reductions all four harvests (two, three, four and five leaf stage) both incorporated and preemergence (Table 6-9).

Table 6. The Effect of Soil Applied Herbicides at Three Rates on Corn Shoot Fresh Weights, Two Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm fresh wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	5.1 a	1.8 ab	5.4 a	1.9 a	5.1 bc	1.8 a
Alachlor, PRE	5.8 a	2.0 ab	5.7 a	1.9 a	6.5 a	2.1 a
Metolachlor, PPI	5.1 a	1.9 ab	5.0 a	2.0 a	5.5 abc	1.8 a
Metolachlor, PRE	5.7 a	2.1 ab	6.1 a	2.0 a	6.0 abc	1.8 a
Acetochlor, PPI	5.3 a	1.6 b	-	2.1 a	4.8 c	1.8 a
Acetochlor, PRE	5.4 a	1.6 b	6.2 a	1.9 a	5.5 abc	1.6 a
Butyalte+R-25788, PPI	6.0 a	2.2 a	5.6 a	1.9 a	5.7 abc	1.7 a
EPTC+R-25788, PPI	5.8 a	2.0 ab	-	-	-	-
Pendimethalin, PRE	6.2 a	1.9 ab	-	-	-	-
Untreated	5.5 a	2.0 ab	5.5 a	2.0 a	5.5 abc	2.0 a

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Table 7. The Effect of Soil Applied Herbicides at Three Rates on Corn Shoot Fresh Weights, Three Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm fresh wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	9.5 a	4.1 ab	7.9 b	3.6 a	9.2 a	3.2 b
Alachlor, PRE	9.1 a	4.0 ab	10.6 a	4.1 a	11.0 a	3.2 b
Metolachlor, PPI	9.4 a	3.7 ab	9.0 ab	3.8 a	8.6 ab	3.6 ab
Metolachlor, PRE	9.7 a	3.5 ab	9.2 ab	3.7 a	10.7 a	3.8 ab
Acetochlor, PPI	8.8 a	3.3 b	-	3.7 a	6.6 b	3.0 b
Acetochlor, PRE	9.7 a	3.8 ab	10.2 ab	3.6 a	9.9 a	3.1 ab
Butylate+R-25788, PPI	9.2 a	4.5 a	9.3 ab	3.4 a	10.0 a	3.6 ab
EPTC+R-25788, PPI	8.7 a	3.4 b	-	-	-	-
Pendimethalin, PRE	11.2 a	3.8 ab	-	-	-	-
Untreated	9.4 a	4.0 ab	9.4 ab	4.0 a	9.4 a	4.0 a

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Table 8. The Effect of Soil Applied Herbicides at Three Rates on Corn Shoot Fresh Weights, Four Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm fresh wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	29.6 a	15.3 a	29.8 a	13.8 ab	30.2 ab	11.4 abc
Alachlor, PRE	36.3 a	15.9 a	30.0 ab	16.9 a	42.1 a	14.1 ab
Metolachlor, PPI	37.5 a	14.3 a	28.2 ab	14.8 ab	36.2 a	14.7 ab
Metolachlor, PRE	29.4 a	16.0 a	32.8 ab	13.9 ab	37.2 a	15.1 a
Acetochlor, PPI	31.4 a	11.4 a	19.5 b	9.3 b	17.9 b	7.7 c
Acetochlor, PRE	33.4 a	15.1 a	40.5 a	13.1 ab	30.3 ab	8.9 bc
Butylate+R-25788, PPI	38.9 a	16.1 a	31.5 ab	13.1 ab	30.3 ab	13.6 ab
EPTC+R-25788, PPI	28.4 a	15.0 a	-	-	-	-
Pendimethalin, PRE	33.8 a	17.0 a	-	-	-	-
Untreated	43.6 a	16.4 a	43.6 a	16.4 a	43.6 a	16.4 a

[a]Means, averages of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Table 9. The Effect of Soil Applied Herbicides at Three Rates on Corn Shoot Fresh Weights, Five Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm fresh wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	116.4 ab	85.7 a	103.3 a	80.8 ab	107.0 a	55.0 abc
Alachlor, PRE	127.8 ab	96.3 a	114.8 a	97.4 a	151.2 a	69.6 abc
Metolachlor, PPI	152.3 a	83.9 a	148.8 a	73.0 ab	106.2 a	63.1 abc
Metolachlor, PRE	106.2 ab	76.5 a	131.5 a	54.2 ab	125.6 a	67.8 abc
Acetochlor, PPI	112.0 ab	61.0 a	-	39.6 b	-	30.0 bc
Acetochlor, PRE	122.3 ab	66.3 a	121.9 a	39.9 b	103.8 a	28.6 c
Butylate+R-25788, PPI	134.7 ab	78.7 a	100.5 a	65.4 ab	126.4 a	83.2 a
EPTC+R-25788, PPI	81.6 b	90.4 a	-	-	-	-
Pendimethalin, PRE	158.7 a	70.1 a	-	-	-	-
Untreated	148.8 ab	82.2 a	148.8 a	82.2 ab	148.8 a	82.2 a

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Differences between incorporated and preemergence treatments occurred only during 1982. Preemergence alachlor harvest 1 and 2, and acetochlor preemergence harvest 2 and 3 showed significant increases in shoot fresh weights compared to the incorporated treatment at the same rate (Table 6-8).

Shoot and root fresh weight values were lower in 1983 than in 1982. The greatest differences were in shoot weights rather than the root weights. The temperatures were lower early in the growing season in 1983, combined with more rainfall (Appendix 9) and later planting date in 1983 could all cause reductions in plant weights.

Diffusive Resistance

Differences in root and shoot growth with the various herbicide treatments did not translate into differences in diffusive resistance as measured with the porometer (Appendix 15). Herbicide treatments did not alter the diffusive resistance with the exception of acetochlor at the 4X rate preemergence on June 22, 1982 (Table 10). Acetochlor increased the diffusive resistance, indicating increased water stress.

Leaf Water Potential

None of the herbicide treatments significantly affected the leaf water potential as measured with the pressure chamber from that of the control (Table 11). However, incorporated acetochlor had a significantly lower

Table 10. The Effect of Soil Applied Herbicides at Three Rates on Diffusive Resistance in Corn.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	seconds/cm					
	6/22/82	6/14/83	6/22/82	6/14/83	6/22/82	6/14/83
Alachlor, PPI	2.45 a	1.68 a	2.64 a	1.74 a	1.84 ab	1.59 a
Alachlor, PRE	1.75 a	1.67 a	1.77 a	1.70 a	1.99 ab	1.39 a
Metolachlor, PPI	2.62 a	1.59 a	2.60 a	1.78 a	1.90 ab	1.59 a
Metolachlor, PRE	2.15 a	1.67 a	2.56 a	1.33 a	2.57 ab	1.67 a
Acetochlor, PPI	2.26 a	1.83 a	2.62 a	2.01 a	2.19 ab	2.20 a
Acetochlor, PRE	1.89 a	1.48 a	1.87 a	1.35 a	2.77 a	1.50 a
Butylate+R-25788, PPI	2.49 a	1.96 a	2.03 a	1.83 a	2.20 ab	1.74 a
EPTC+R-25788, PPI	2.63 a	1.97 a	-	-	-	-
Pendimethalin, PRE	2.12 a	1.77 a	-	-	-	-
Untreated	1.75 a	1.58 a	1.75 a	1.58 a	1.75 b	1.58 a

[a]Means within one column followed by the same letter are not significantly different using Duncan's multiple range test at the 5% level.

[b]See figure two.

Table 11. The Effect of Soil Applied Herbicides at Three Rates on Corn Leaf Water Potential.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	bars					
	6/22/82	6/23/82	6/22/82	6/23/82	6/22/82	6/23/82
Alachlor, PPI	9.8 a	7.5 ab	8.6 a	7.6 a	9.6 a	7.4 a
Alachlor, PRE	10.1 a	7.6 ab	10.4 a	7.8 a	9.3 a	7.6 a
Metolachlor, PPI	9.2 a	7.8 ab	9.1 a	7.8 a	9.4 a	7.5 a
Metolachlor, PRE	9.6 a	7.6 ab	8.7 a	7.8 a	9.3 a	7.7 a
Acetochlor, PPI	9.5 a	8.9 a	9.5 a	8.1 a	9.8 a	8.3 a
Acetochlor, PRE	9.7 a	6.7 b	9.1 a	7.4 a	9.4 a	8.1 a
Butylate+R-25788, PPI	10.3 a	7.3 ab	10.4 a	7.6 a	10.4 a	7.7 a
EPTC+R-25788, PPI	9.3 a	8.1 ab	-	-	-	-
Pendimethalin, PRE	9.4 a	7.4 ab	-	-	-	-
Untreated	9.0 a	7.6 ab	9.0 a	7.6 a	9.0 a	7.6 a

[a]Means within one column followed by the same letter are not significantly different using Duncan's multiple range test at the 5% level.

[b]See figure two.

water potential at the 1X rate on June 23, 1982.

Corn Leaf Nutrient Analysis

Potassium content was not significantly affected by the herbicide treatment except for acetochlor preemergence at the 4X rate in 1982 (Table 12). All of the herbicide treatments in 1982 with the exception of acetochlor incorporated at the 4X rate were within the normal (36) range of 1.7 to 2.5 percent potassium. All of the values for 1983 were just at or below the normal range and were considered low in potassium content, 1.26 to 1.70 percent. The percent possible analytical error as determined from the blank sample (Appendix 15) was 0.03 percent both years. Plants treated with acetochlor preemergence in 1982 were significantly higher in potassium concentration than plants in the incorporated treatment at the 4X rate.

No herbicide treatment significantly reduced phosphorus content from that of the control (Table 13). All values were within the normal range of 0.25 to 0.50 percent phosphorus (36). The percent analytical error as determined from the blank sample was 0.02 and 0.003 percent in 1982 and 1983. Plants treated with alachlor incorporated were significantly higher in phosphorus content than plants treated with pendimethalin both years, alachlor and metolachlor preemergence, and EPTC+R-25788 in 1982. Alachlor incorporated at the 2X in 1982 and the 4X rate in 1983 produced higher phosphorus contents than

Table 12. The Effect of Soil Applied Herbicides at Three Rates on Corn Leaf Potassium Content, Sampled at Silking.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	% K					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	2.1 a	1.3 b	1.9 a	1.5 a	1.8 abc	1.6 a
Alachlor, PRE	2.0 a	1.7 ab	2.0 a	1.6 a	2.0 ab	1.6 a
Metolachlor, PPI	1.9 a	1.4 ab	1.8 a	1.8 a	1.8 abc	1.7 a
Metolachlor, PRE	2.0 a	1.8 a	1.8 a	1.5 a	1.9 abc	1.6 a
Acetochlor, PPI	1.7 a	1.6 ab	1.8 a	1.7 a	1.5 c	1.5 a
Acetochlor, PRE	1.8 a	1.6 ab	1.8 a	1.4 a	2.2 a	1.6 a
Butylate+R-25788, PPI	1.8 a	1.6 ab	1.8 a	1.5 a	1.9 abc	1.7 a
EPTC+R-25788, PPI	1.7 a	1.5 ab	-	-	-	-
Pendimethalin, PRE	2.0 a	1.6 ab	-	-	-	-
Untreated	1.7 a	1.6 ab	1.7 a	1.6 a	1.7 bc	1.6 a

[a]Means within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

Table 13. The Effect of Soil Applied Herbicides at Three Rates on Corn Leaf Phosphorus Content, Sampled at Silking.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	% P					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	0.40 a	0.31 a	0.37 a	0.29 a	0.34 a	0.30 a
Alachlor, PRE	0.30 bc	0.30 ab	0.28 b	0.27 a	0.34 a	0.25 c
Metolachlor, PPI	0.35 ab	0.28 ab	0.33 ab	0.30 a	0.32 a	0.30 a
Metolachlor, PRE	0.29 bc	0.28 a	0.30 ab	0.28 a	0.30 a	0.27 abc
Acetochlor, PPI	0.32 abc	0.28 ab	0.28 b	0.30 a	0.33 a	0.29 ab
Acetochlor, PRE	0.33 abc	0.28 ab	0.30 ab	0.27 a	0.33 a	0.26 bc
Butylate+R-25788, PPI	0.33 abc	0.28 ab	0.31 ab	0.27 a	0.28 a	0.29 ab
EPTC+R-25788, PPI	0.29 bc	0.28 ab	-	-	-	-
Pendimethalin, PRE	0.25 c	0.27 b	-	-	-	-
Untreated	0.33 abc	0.28 ab	0.33 ab	0.27 a	0.33 a	0.27 abc

[a]Means within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

other treatments at the same 4X rate during 1983 (Table 13).

Corn Grain Yield

At normal use rates, no herbicide treatment reduced corn grain yield. At higher rates, acetochlor incorporated and preemergence was the only herbicide treatment to significantly reduce corn yields (Table 14). Preemergence acetochlor treatments had higher yields than the incorporated treatment at the same rate during 1982 and 1983. The yields of the four varieties are listed in the appendix (10-13).

Table 14. The Effect of Soil Applied Herbicides at Three Rates on Corn Grain Yield.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	kg/ha					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	6832 a	5814 a	5010 ab	5540 a	7727 a	5437 ab
Alachlor, PRE	6820 a	5512 a	7599 a	5578 a	8853 a	5771 ab
Metolachlor, PPI	5631 a	5727 a	6585 a	5629 a	5960 a	5564 ab
Metolachlor, PRE	6954 a	5726 a	7355 a	5498 a	7502 a	6063 a
Acetochlor, PPI	4424 a	5537 a	2786 b	4996 a	2671 b	3317 c
Acetochlor, PRE	6866 a	5395 a	7849 a	5375 a	6914 a	4766 b
Butylate+R-25788, PPI	5709 a	5526 a	7150 a	5406 a	6126 a	5434 ab
EPTC+R-25788, PPI	6154 a	5767 a	-	-	-	-
Pendimethalin, PRE	7435 a	5606 a	-	-	-	-
Untreated	7230 a	5360 a	7230 a	5360 a	7230 a	5360 ab

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

CONCLUSIONS

Herbicide treatments produced reductions in germination, growth, water stress and nutrient uptake that affected corn plants during the growing season, which is in agreement with the authors cited. The reductions in root and shoot weights were more evident at the third harvest, which is similar to the results obtained by Buzio and Burt (13) who found that the greatest injury to corn from EPTC+R-25788 occurred four weeks after planting. However, corn grain yield was not significantly changed as a direct result of any of the parameters studied at normal use rates under normal field conditions. Alachlor, metolachlor, butylate+R-25788, EPTC+R-25788 and pendimethalin at normal use rates are all comparatively safe and the differences observed do not have a direct effect on yield.

Denmead and Shaw found that early season stress could indirectly affect corn yield (23). Yield of corn could be indirectly affected by any one or combination of the parameters studied. Several questions concerning the comparative effects of the soil applied herbicides in corn are still unanswered. Some comparisons that should be given consideration for further study are:

1. Effects of the soil applied herbicides under

increasing/decreasing water stress.

2. Effects of the soil applied herbicides on plant nutrient uptake under high and low fertility levels.

3. Effects of the persistance or injury caused by the soil applied herbicides should be measured in the plant and soil and expressed as a function of the parameters involved in corn growth i.e. a certain plant process is affected by a herbicide up through a certain growth stage.

4. Effects of extenders or lay by applications which could possibly allow the active herbicide to be in the soil and plant through pollination which could affect yield.

5. Effects on the biomass of corn for silage or the effect of the soil applied herbicides on the maturity of corn.

Greater differences were observed during corn growth with increased rates of herbicides (2X, 4X) as compared to the normal use rates (1X). Though the herbicides are not recommended at these rates, these data present a good indication of the margin of safety of these herbicides. From the overall observations of the author, the herbicide that showed the least reduction at higher rates in growth and stress in the corn plants earlier in the growing season was butylate+R-25788. However, the butylate+R-25788 treatment did not show any increases in yield as compared to the alachlor or metolachlor treatments. Acetochlor produced the greatest reductions in growth and stress as compared

to the other herbicides at the higher rates.

The differences between incorporated and preemergence treatments may have occurred in the drier year, 1982, (Appendix 9) because the preemergence herbicides were not placed in the root zone of the corn as well as the incorporated treatments. Since the root growth is affected more than shoot growth by the soil applied herbicides as seen in this study, if a herbicide were not in the root zone of a corn plant, the plant would not be affected as much by a preemergence treatment. Differences between incorporated and preemergence treatments did not result in significant changes in yield, with the exception of acetochlor at higher rates. Yield was most directly affected by the stand loss caused by the acetochlor treatment.

SUMMARY

The effect of alachlor (2-chloro-2',6'-diethyl-N-(methoxymethyl)acetanilide), metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide), acetochlor (2-chloro-N(ethoxymethyl)-6'-ethyl-o-acetotoluidide), butylate + R-25788 (S-ethyl diisobutyl thiocarbamate + N,N-dially-2,2-dichloroacetamide), EPTC + R-25788 (S-ethyl dipropylthiocarbamate + N,N-dially-2,2-dichloroacetamide), and pendimethalin (N-(1-ethylpropyl)-3,4 dimethyl-2,6 dinitrobenzenamine) on corn plant population, root and shoot fresh and dry weights, diffusive resistance and leaf water potential, leaf nutrient content at silking, and yield was studied in 1982 and 1983. Herbicides were evaluated for their effect on corn growth with herbicide treatments at normal use rates (1X), increasing rates of herbicides (2X, 4X) excluding EPTC + R-25788 and pendimethalin, and both preplant incorporated and preemergence with alachlor, metolachlor, and acetochlor.

Root weights were affected more than the shoot weights. Root and shoot weights were less in 1983 than in 1982 at the same harvest, with the shoot weights showing greater differences between the two years. Differences in root and shoot weights were observed more

the third harvest.

Acetochlor preplant incorporated showed the greatest reduction in all of the parameters studied.

EPTC + R-25788 showed greater reduction in root and shoot weights than alachlor, metolachlor, butylate + R-25788 and pendimethalin. Alachlor preplant incorporated was significantly different in phosphorus content as compared to pendimethalin and preemergence alachlor treatments, but all three were within the sufficiency ranges for corn.

Though differences were observed with alachlor, metolachlor, butylate + R-25788, EPTC + R-25788 and pendimethalin at all rates and methods of application, yield was not significantly reduced by any treatment.

In conclusion, alachlor, metolachlor, butylate + R-25788, EPTC + R-25788 and pendimethalin should be considered comparatively safe in their effect on corn growth under normal conditions and at recomended rates. In reporting data on corn growth one should consider the total picture portrayed on the growth of corn as it is affected by soil applied herbicides.

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APPENDICES

Appendix 1. The Effect of Soil Applied Herbicides at Three Rates on Corn Root Dry Weights, Two Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm dry wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	0.59 ab	0.17 bc	0.55 a	0.18 a	0.60 a	0.19 ab
Alachlor, PRE	0.71 ab	0.17 bc	0.63 a	0.18 a	0.79 a	0.19 ab
Metolachlor, PPI	0.68 ab	0.20 ab	0.45 a	0.20 a	0.64 a	0.19 ab
Metolachlor, PRE	0.55 ab	0.19 abc	0.62 a	0.19 a	0.58 a	0.17 b
Acetochlor, PPI	0.78 a	0.18 abc	-	0.19 a	-	0.19 ab
Acetochlor, PRE	0.60 ab	0.16 c	0.72 a	0.19 a	0.53 a	0.19 ab
Butylate+R-25788, PPI	0.72 ab	0.20 ab	0.64 a	0.19 a	0.71 a	0.18 ab
EPTC+R-25788, PPI	0.65 ab	0.18 abc	-	-	-	-
Pendimethalin, PRE	0.46 b	0.18 abc	-	-	-	-
Untreated	0.52 ab	0.21 a	0.52 a	0.21 a	0.52 a	0.21 a

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Appendix 2. The Effect of Soil Applied Herbicides at Three Rates on Corn Root Dry Weights, Three Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm dry wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	0.65 ab	0.31 ab	0.56 a	0.31 a	0.54 ab	0.21 d
Alachlor, PRE	0.64 ab	0.26 bc	0.69 a	0.30 ab	0.70 ab	0.24 cd
Metolachlor, PPI	0.58 ab	0.30 abc	0.62 a	0.30 ab	0.50 bc	0.30 ab
Metolachlor, PRE	0.72 ab	0.27 abc	0.69 a	0.30 ab	0.71 a	0.24 cd
Acetochlor, PPI	0.54 b	0.26 bc	-	0.26 bc	0.33 c	0.27 bc
Acetochlor, PRE	0.69 ab	0.25 c	0.71 a	0.23 c	0.61 ab	0.21 d
Butylate+R-25788, PPI	0.77 a	0.32 a	0.75 a	0.30 ab	0.57 ab	0.32 a
EPTC+R-25788, PPI	0.67 ab	0.26 bc	-	-	-	-
Pendimethalin, PRE	0.75 a	0.27 abc	-	-	-	-
Untreated	0.69 ab	0.29 abc	0.69 a	0.29 ab	0.69 ab	0.29 ab

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Appendix 3. The Effect of Soil Applied Herbicides at Three Rates on Corn Root Dry Weights, Four Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm dry wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	1.10 ab	0.98 ab	0.98 abc	0.84 bc	1.15 ab	0.72 ef
Alachlor, PRE	1.13 ab	0.87 b	0.90 bc	0.94 abc	0.99 ab	0.79 de
Metolachlor, PPI	1.14 ab	0.98 ab	0.90 bc	0.88 bc	0.91 bc	1.01 abc
Metolachlor, PRE	1.25 ab	0.92 b	0.92 bc	0.87 bc	1.04 ab	0.92 bcde
Acetochlor, PPI	0.88 b	0.86 b	0.78 c	0.63 d	0.56 c	0.55 f
Acetochlor, PRE	1.00 ab	0.93 ab	1.13 abc	0.80 cd	0.88 bc	0.52 f
Butylate+R-25788, PPI	1.04 ab	0.97 ab	1.06 abc	0.84 bc	0.96 bc	0.87 cde
EPTC+R-25788, PPI	0.89 b	0.95 ab	-	-	-	-
Pendimethalin, PRE	1.08 ab	1.05 ab	-	-	-	-
Untreated	1.38 a	1.14 a	1.38 a	1.14 a	1.38 a	1.14 a

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Appendix 4. The Effect of Soil Applied Herbicides at Three Rates on Corn Root Dry Weights, Five Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm dry wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	2.58 ab	2.96 a	2.91 a	2.62 ab	2.56 a	1.94 bcd
Alachlor, PRE	2.92 ab	2.77 a	2.74 a	2.84 a	3.17 a	2.23 abc
Metolachlor, PPI	3.21 ab	2.67 a	3.16 a	2.45 ab	2.43 a	2.29 abc
Metolachlor, PRE	2.60 ab	2.76 a	2.90 a	2.15 ab	2.85 a	2.45 ab
Acetochlor, PPI	2.98 ab	2.12 a	-	1.69 b	-	1.35 cd
Acetochlor, PRE	2.71 ab	2.49 a	2.99 a	2.06 ab	2.58 a	1.26 d
Butylate+R-25788, PPI	2.77 ab	2.77 a	2.50 a	2.29 ab	2.79 a	2.58 ab
EPTC+R-25788, PPI	2.18 b	2.69 a	-	-	-	-
Pendimethalin, PRE	3.60 a	2.65 a	-	-	-	-
Untreated	3.23 ab	3.12 a	3.23 a	3.02 a	3.23 a	3.02 a

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Appendix 5. The Effect of Soil Applied Herbicides at Three Rates on Corn Shoot Dry Weights, Two Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm dry wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	0.67 a	0.19 ab	0.64 bcd	0.20 a	0.75 bcd	0.19 a
Alachlor, PRE	0.87 a	0.20 ab	0.82 abcd	0.19 a	1.05 a	0.21 a
Metolachlor, PPI	0.83 a	0.19 ab	0.59 d	0.21 a	0.79 bcd	0.20 a
Metolachlor, PRE	0.67 a	0.21 ab	0.90 ab	0.21 a	0.80 abcd	0.19 a
Acetochlor, PPI	0.74 a	0.18 ab	0.62 cd	0.21 a	0.58 d	0.19 a
Acetochlor, PRE	0.74 a	0.17 b	0.95 a	0.19 a	0.74 bcd	0.18 a
Butylate+R-25788, PPI	0.84 a	0.22 a	0.79 abcd	0.19 a	0.80 abcd	0.18 a
EPTC+R-25788, PPI	0.78 a	0.21 ab	-	-	-	-
Pendimethalin, PRE	0.69 a	0.19 ab	-	-	-	-
Untreated	0.66 a	0.21 ab	0.66 bcd	0.21 a	0.66 cd	0.21 a

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Appendix 6. The Effect of Soil Applied Herbicides at Three Rates on Corn Shoot Dry Weights, Three Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm dry wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	2.15 ab	0.45 ab	1.51 b	0.46 a	1.78 bcd	0.37 bc
Alachlor, PRE	1.99 ab	0.46 ab	2.35 a	0.49 a	2.58 a	0.37 bc
Metolachlor, PPI	2.10 ab	0.43 ab	1.91 ab	0.44 a	1.72 cd	0.46 ab
Metolachlor, PRE	2.16 ab	0.44 ab	2.02 ab	0.46 a	2.54 ab	0.42 abc
Acetochlor, PPI	1.84 b	0.39 b	-	0.39 a	1.08 d	0.37 bc
Acetochlor, PRE	2.19 ab	0.43 ab	2.43 a	0.40 a	2.03 abc	0.32 c
Butylate+R-25788, PPI	2.14 ab	0.52 a	2.15 ab	0.43 a	2.24 abc	0.47 ab
EPTC+R-25788, PPI	1.90 ab	0.40 b	-	-	-	-
Pendimethalin, PRE	2.65 a	0.42 ab	-	-	-	-
Untreated	2.11 ab	0.49 ab	2.11 ab	0.49 a	2.11 abc	0.49 a

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Appendix 7. The Effect of Soil Applied Herbicides at Three Rates on Corn Shoot Dry Weights, Four Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm dry wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	6.01 ab	2.04 a	5.13 ab	1.77 ab	5.62 ab	1.43 ab
Alachlor, PRE	6.83 ab	1.99 a	5.55 ab	2.14 a	8.13 a	1.72 a
Metolachlor, PPI	7.60 ab	1.90 a	5.13 ab	1.91 a	6.62 a	2.09 a
Metolachlor, PRE	5.15 ab	2.07 a	5.93 ab	1.81 ab	6.28 ab	1.96 a
Acetochlor, PPI	5.95 ab	1.54 a	3.70 b	1.21 b	2.73 b	1.01 b
Acetochlor, PRE	6.44 ab	1.92 a	7.82 a	1.57 ab	5.48 ab	1.04 b
Butylate+R-25788, PPI	7.58 ab	2.14 a	6.02 ab	1.69 ab	5.21 ab	1.77 a
EPTC+R-25788, PPI	4.93 b	2.07 a	-	-	-	-
Pendimethalin, PRE	6.29 ab	2.16 a	-	-	-	-
Untreated	8.80 a	2.11 a	8.80 a	2.11 a	8.80 a	2.11 a

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Appendix 8. The Effect of Soil Applied Herbicides at Three Rates on Corn Shoot Dry Weights, Five Leaf Stage.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	gm dry wt[c]					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	11.42 ab	9.42 a	10.39 a	8.68 a	10.47 a	6.21 abc
Alachlor, PRE	12.49 ab	10.63 a	11.15 a	10.44 a	14.52 a	7.09 abc
Metolachlor, PPI	14.69 a	8.64 a	13.71 a	8.41 a	10.75 a	7.12 abc
Metolachlor, PRE	10.38 ab	8.20 a	12.26 a	6.14 a	12.41 a	7.44 abc
Acetochlor, PPI	11.32 ab	6.71 a	-	5.03	-	3.66 bc
Acetochlor, PRE	11.50 ab	7.43 a	12.80 a	4.98 a	10.83 a	3.47 c
Butylate+R-25788, PPI	12.81 ab	9.03 a	9.93 a	8.28 a	12.39 a	9.19 a
EPTC+R-25788, PPI	7.56 b	10.08 a	-	-	-	-
Pendimethalin, PRE	15.50 a	7.83 a	-	-	-	-
Untreated	13.92 ab	8.84 a	13.92 a	8.84 a	13.92 a	8.84 abc

[a]Means, average of four varieties, within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

[c]Weight of five plants.

Appendix 9. Rainfall Data for 1982 and 1983, Crop Science Research Farm - East Lansing, Michigan.

	April		May		June	
Day	1982	1983	1982	1983	1982	1983
1				.41	1.41	.02
2				1.16		
3	.30			.11		
4		.79		.02	.12	.65
5		.04				.02
6	.50	.13				.22
7		.31		.06		.18
8			.31	.94	.12	
9						
10		.40			.20	
11		.02				
12						
13	.14	.20	.12			
14		.88				
15		.11		.08	.10	
16			.19		.72	.18
17	.04	.15	.06			
18		.05				
19			.14		.73	
20	.16		.57	.83		
21						
22			.42			
23			.09	1.00		
24						
25				.04		
26				.32		
27			.04		.14	.32
28		.38	.44			3.28
29		.63		.39	.35	.16
30		.06		.07		
31				.16		
TOTAL	1.14	4.15	2.38	5.59	3.97	5.03

Appendix 10. The Effect of Soil Applied Herbicides at Three Rates on Corn Grain Yield, Voris 2381.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	kg/ha					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	6147 ab	4957 a	6973 a	4541 a	7958 a	4880 a
Alachlor, PRE	6598 ab	4721 a	8362 a	4456 a	8123 a	5265 a
Metolachlor, PPI	5525 ab	4508 a	7346 a	5168 a	5497 a	3633 a
Metolachlor, PRE	6576 ab	4778 a	6973 a	5077 a	7673 a	4680 a
Acetochlor, PPI	3661 b	4471 a	3677 b	4175 a	2041 b	2174 b
Acetochlor, PRE	6310 ab	4829 a	8073 a	3848 a	7756 a	4086 a
Butylate+R-25788, PPI	4820 ab	4432 a	6291 ab	4749 a	5357 a	4538 a
EPTC+R-25788, PPI	6285 ab	5014 a	-	-	-	-
Pendimethalin, PRE	7569 a	5154 a	-	-	-	-
Untreated	7017 a	4135 a	7017 a	4135 a	7017 a	4135 a

[a]Means within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

Appendix 11. The Effect of Soil Applied Herbicides at Three Rates on Corn Grain Yield, Great Lakes 422.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	kg/ha					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	4886 a	6740 a	3689 bc	6142 a	5754 abc	6388 a
Alachlor, PRE	5503 a	5323 a	6033 ab	6418 a	8334 a	6426 a
Metolachlor, PPI	5204 a	6814 a	5542 abc	6018 a	4989 bcd	6997 a
Metolachlor, PRE	4655 a	6068 a	6216 ab	5696 a	6471 abc	6619 a
Acetochlor, PPI	3348 a	6448 a	2606 c	5656 a	2176 d	4297 c
Acetochlor, PRE	6589 a	5472 a	7645 a	5566 a	7002 abc	4479 bc
Butylate+R-25788, PPI	4800 a	6018 a	6698 ab	5390 a	4267 cd	5634 ab
EPTC+R-25788, PPI	6039 a	6062 a	-	-	-	-
Pendimethalin, PRE	5557 a	5836 a	-	-	-	-
Untreated	6413 a	5799 a	6413 ab	5799 a	6413 abc	5799 a

[a]Means within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

Appendix 12. The Effect of Soil Applied Herbicides at Three Rates on Corn Grain Yield, Voris 2331.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	kg/ha					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	8004 ab	6300 a	4570 bc	5939 a	9066 ab	6015 abc
Alachlor, PRE	7599 abc	5787 a	6976 ab	5850 a	9455 a	5587 abc
Metolachlor, PPI	5066 bc	5753 a	6974 ab	5804 a	6770 abcd	5993 abc
Metolachlor, PRE	8710 a	5848 a	8246 a	5649 a	8516 ab	6683 a
Acetochlor, PPI	4580 c	6499 a	3229 c	5672 a	3561 d	4706 c
Acetochlor, PRE	7471 abc	5311 a	7400 ab	5434 a	4920 cd	4886 bc
Butylate+R-25788, PPI	6231 abc	6302 a	8026 a	5364 a	5953 bcd	6044 abc
EPTC+R-25788, PPI	5710 abc	5938 a	-	-	-	-
Pendimethalin, PRE	8224 ab	5783 a	-	-	-	-
Untreated	7314 abc	5962 a	7314 ab	5962 a	7314 abc	5962 abc

[a]Means within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

Appendix 13. The Effect of Soil Applied Herbicides at Three Rates on Corn Grain Yield, Pioneer 3901.[a]

Herbicide and Application	Rate[b] 1X		2X		4X	
	kg/ha					
	1982	1983	1982	1983	1982	1983
Alachlor, PPI	8292 a	5260 a	4815 bc	5539 ab	8130 a	4469 b
Alachlor, PRE	7579 a	6219 a	9026 a	5590 ab	9501 a	5812 ab
Metolachlor, PPI	6730 a	5835 a	6481 ab	5528 ab	6584 a	5635 ab
Metolachlor, PRE	7873 a	6215 a	7985 ab	5574 ab	7347 a	6272 a
Acetochlor, PPI	6109 a	4732 a	1631 c	4482 b	2907 b	2092 c
Acetochlor, PRE	7095 a	5969 a	8279 a	6651 a	7977 a	5614 ab
Butylate+R-25788, PPI	6983 a	5354 a	7585 ab	6121 ab	8926 a	5521 ab
EPTC+R-25788, PPI	5584 a	6056 a	-	-	-	-
Pendimethalin, PRE	8389 a	5647 a	-	-	-	-
Untreated	8174 a	5544 a	8174 a	5544 ab	8174 a	5544 ab

[a]Means within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.

Appendix 14. Sample Procedure for Plasma Emission Spectroscopy.

1. Weigh 1.000 g of ground plant tissue (20 mesh) in numbered crucible.
2. Dry ash @ 500 C for 5 hrs. in a muffle furnace (include 2 blanks for every batch of 20-25).
3. Cool. Add 5 ml $6NHNO_3$. Swirl.
4. Let stand for 1 hour.
5. Pour through small glass funnel into 10 ml volumetric flask.
6. Adjust volume to 10 ml mark with 1000ppm LiCl (6.08 g LiCl/l).
7. Filter through #2 filter paper into labled vials.
8. This is 10X dilution for micro nutrients.
9. Pipette 0.4 ml of 10X solution to another vial.
10. Add 19.6 ml of 1000 ppm LiCl. This is 500X dilution for macro nutrients.

Appendix 15. The Effect of Soil Applied Herbicides at Three Rates on Diffusive Resistance in Corn, May 11 and June 23, 1982.

Herbicide and Application	Rate[b] 1X		2X		4X	
	seconds/cm					
	5/11/82	6/23/82	5/11/82	6/23/82	5/11/82	6/23/82
Alachlor, PPI	2.07 a	1.85 a	2.24 a	2.39 a	2.44 a	1.97 a
Alachlor, PRE	2.14 a	1.95 a	1.80 a	1.80 a	1.81 a	1.93 a
Metolachlor, PPI	2.14 a	2.14 a	2.24 a	2.82 a	2.10 a	1.83 a
Metolachlor, PRE	2.37 a	1.93 a	2.17 a	2.22 a	1.70 a	2.11 a
Acetochlor, PPI	2.24 a	1.99 a	2.62 a	2.26 a	2.32 a	2.23 a
Acetochlor, PRE	1.92 a	1.89 a	1.88 a	2.15 a	1.67 a	1.91 a
Butylate+R-25788, PPI	1.97 a	2.30 a	2.23 a	2.37 a	2.25 a	1.81 a
EPTC+R-25788, PPI	2.12 a	1.86 a	-	-	-	-
Pendimethalin, PRE	1.99 a	1.93 a	-	-	-	-
Untreated	1.76 a	2.10 a	1.76 a	2.10 a	1.76 a	2.10 a

[a]Means within one column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b]See figure two.