To the Graduate Council:

I am submitting herewith a thesis written by John Michael Kennedy entitled "Thiocarbamate and Antidote Effects on Corn Hybrids." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

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THIOCARBAMATE AND ANTIDOTE EFFECTS ON CORN HYBRIDS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

John Michael Kennedy

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ABSTRACT

Selected corn (Zea mays L.) hybrids were evaluated for their response to thiocarbamate herbicides at three Tennessee locations: the West Tennessee Experiment Station, Jackson; Milan Field Station, Milan; and the Plant Science Field Laboratory, Knoxville, during 1977. Nine corn hybrids selected for thiocarbamate herbicide response in 1976 were evaluated. The Jackson test was primarily an herbicide rate study of the susceptibility of the corn hybrids to EPTC (S-ethyl dipropylthiocarbamate) or butylate (S-ethyl diisobutylthiocarbamate), in formulations with the herbicide antidote R-25788 (N,N-diallyl-2,2-dichloroacetamide) at 4.5 kg/ha, and 6.9 kg/ha. At Milan the response of corn to EPTC or butylate in formulations with the herbicide antidotes R-25788 or R-29148 (2,2,5 trimethyl-N-dichloroacetyloxazotidine) were compared. The Knoxville test compared the corn response to vernolate (S-propyl dipropylthiocarbamate) with both antidotes, also EPTC and R-12001 (S-isopropyl 5-ethyl-2-methyl-piperidine-1-carbothioate) in combination with R-25788.

Data were obtained throughout the growing season on corn injury symptoms which included wrinkled or folded leaves, bent stalks, deformed husks, increased tillering, smut occurrence, and reduced grain yield.

DeKalb XL55, treated with EPTC + R-25788, exhibited the largest number of injured plants, increased tillering, smut infestation and yield reduction at all locations. DeKalb XL55 treated with vernolate + R-29148 was injured with decreased yield.

In Knoxville, vernolate with either antidote caused the most yield reduction. The grain yields of McNair X210, P.A.G. 644W, Pioneer brand 3369A, and Pioneer brand 3147 were reduced when treated with vernolate + R-25788 while vernolate + R-29148 reduced the yield of DeKalb XL55 and P.A.G. 644W.

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CHAPTER I

INTRODUCTION

Thiocarbamate herbicides provide good weed control in corn (*Zea mays* L.). They control highly competitive weeds such as nutsedge (*Cyperus* spp.), seedling Johnsongrass (*Sorghum halepense* (L.) Pers.), and wild cane (*Sorghum bicolor* L.). Unfortunately these herbicides damage corn hybrids. Antidotes which prevent thiocarbamate herbicide injury have been developed for corn. These antidotes allow higher rates of thiocarbamate herbicides to be used for the control of rhizome Johnsongrass. However, under certain conditions and with certain corn hybrids thiocarbamate herbicide injury can occur even when an antidote is used.

The purpose of this study was to compare the response of nine corn hybrids to thiocarbamate herbicide-antidote combinations.

CHAPTER II

LITERATURE REVIEW

Herbicide Physical Properties

The common name, chemical name and chemical structures of the herbicides and antidotes may be found in Tables 1 and 2 respectively.

EPTC was the first thiocarbamate herbicide introduced by Stauffer Chemical Company in 1956. It was labeled as an experimental herbicide for control of annual grasses, nutsedge (*Cyperus* spp.) and many broadleaf weeds (32,38).

EPTC has a water solubility of 370 ppm at 30 C, and a vapor pressure of 34×10^{-3} mm at 25 C. The acute oral toxicity (LD_{50}) to male albino rats is 1,652 mg/kg, and the dermal toxicity to albino rabbits is about 10,000 mg/kg. The half life of EPTC in a moist loam soil at 21 to 27 C is approximately one week (41).

Butylate has a water solubility of 45 ppm at 22 C, and a vapor pressure of 13×10^{-3} mm at 25 C. The acute oral toxicity (LD_{50}) to male rats is 4,659 mg/kg, and the dermal toxicity (LD_{50}) to albino rabbits is in excess of 4,640 mg/kg. The half life of butylate in many soils under crop growing conditions is approximately 1.5-3 weeks (41).

Vernolate has a water solubility of 90 ppm at 20 C, and a vapor pressure of 10.4×10^{-3} at 25 C. The acute oral toxicity (LD_{50}) to male albino rats is 1,780 mg/kg, and the acute dermal toxicity (LD_{50}) is

Table 1

THIOCARBAMATE HERBICIDES USED IN THIS STUDY

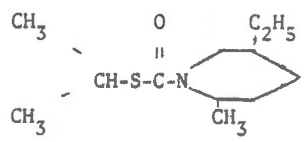
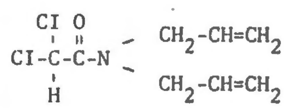
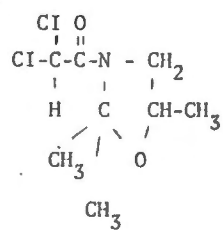
Common Name	Chemical Name	Chemical Structure
EPTC	S-ethyl dipropylthiocarbamate	$CH_3-CH_2-S-\overset{O}{\overset{\parallel}{C}}-N \begin{smallmatrix} CH_2-CH_2-CH_3 \\ CH_2-CH_2-CH_3 \end{smallmatrix}$
Butylate	S-ethyl diisobutylthiocarbamate	$CH_2-CH_2-S-\overset{O}{\overset{\parallel}{C}}-N \begin{smallmatrix} CH_2-CH(CH_3)-CH_3 \\ CH_2-CH(CH_3)-CH_3 \end{smallmatrix}$
Vernolate	S-propyl dipropylthiocarbamate	$CH_3-CH_2-CH_2-S-\overset{O}{\overset{\parallel}{C}}-N \begin{smallmatrix} CH_2-CH_2-CH_3 \\ CH_2-CH_2-CH_3 \end{smallmatrix}$
R-12001	S-isopropyl 5-ethyl-2-methyl-piperidine-1-carbothioate	

Table 2

THIOCARBAMATE HERBICIDE ANTIDOTES USED IN THIS STUDY

Common Name	Chemical Name	Chemical Structure
R-25788	N,N -diallyl-2,2-dichloroacetamide	
R-29148	2,2,5 trimethyl-N-dichloroacetyloxazotidine	

4,640 mg/kg. The half life of vernolate in a moist loam soil at 21 to 27 C is approximately 1.5 weeks (41).

R-12001 is an experimental thiocarbamate herbicide with a water solubility of 38 ppm at 20 C. The acute oral toxicity (LD_{50}) to male rats is 5,010 mg/kg, and to female rats is 3,690 mg/kg. The acute dermal toxicity (LD_{50}) for rabbits is more than 4,640 mg/kg.[1]

Thiocarbamate Antidote Physical Properties

The antidote R-25788 was developed in 1970 by Stauffer Chemical Company, and is used commercially in formulations with EPTC and butylate to protect corn from herbicide injury (32,34,41). When the EPTC or vernolate rate is 6.7 kg/ha, the antidote rate is 0.55 kg/ha, or a 12.2 to 1 herbicide to antidote ratio. Lower antidote rates are used with butylate. R-25788 is used at 0.28 kg/ha when butylate is applied at 6.7 kg/ha, or a 24 to 1 herbicide to antidote ratio. The water solubility of R-25788 is 5,000 ppm at 20 C. The acute oral toxicity (LD_{50}) for female rats is 2,000 mg/kg. The acute dermal toxicity (LD_{50}) for rabbits is more than 4,640 mg/kg. The half life of R-25788 in a moist loam or loamy sand soil is seven to eight days at 27 C (41).

R-29148 is an experimental thicarbamate antidote, so little information is available.

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[1]Anonymous, R-12001 Technical Bulletin (Mountain View, Calif., Stauffer Chemical Co., 1970), pp. 1-3.

Herbicide Behavior in or on Soils

EPTC, butylate and vernolate are absorbed onto dry soil, but can be removed by leaching. Vernolate is more resistant to leaching than is EPTC. Leaching of these herbicides decreases as clay and organic matter increase. In a dry, sandy soil butylate leached about one-third the distance that 20 cm of water moved, while butylate in a heavy clay and organic matter soil only leached slightly with 20 cm of water. Thiocarbamate herbicides are lost by volatilization when the soil surface is wet at the time of application (41).

Temperature is an important factor affecting corn injury by the thiocarbamate herbicides. Burt et al. (6,7,8) found more corn injury at 30 C than at 20 C. Wright and Rieck (45) reported that butylate injury to corn is dependent on the hybrid and temperature. Certain corn hybrids were injured at high temperatures (32 C), whereas other hybrids were injured at cool temperatures.

Wyse et al. (46) found more EPTC injury when navy bean (*Phaseolus vulgaris* L.) was under a high or low moisture stress. Burt et al. (8) found that the effect of moisture on EPTC and butylate corn injury depended upon temperature. At 30 C more injury occurred at 33% soil moisture than at 15% soil moisture, while at 20 C more injury occurred at 15% soil moisture than at 33% soil moisture. No temperature-moisture interaction was observed when R-25788 was added to EPTC or butylate. R-25788 not only reduced EPTC and butylate corn toxicity but also reduced the influence of temperature and soil moisture.

According to Burt (7) the most important factor affecting corn injury by EPTC + R-25788 is the uniformity of soil incorporation of

EPTC + R-25788. Some hybrids were injured at rates as low as 14 ppm when EPTC + R-25788 was poorly incorporated into the soil, but if incorporation was thorough there was no corn seedling injury at rates less than 50 ppm (7).

Depth of seed placement in the soil is critical for thiocarbamate herbicide injury expression. Burt (7) found that corn planted at a 4 cm soil depth was injured more than corn planted at a 2 cm soil depth. Corn with coleoptiles pointing up were injured less than corn planted coleoptile down. Seed planted horizontally was injured less if the anterior side was facing up instead of down. If it is assumed that EPTC is taken up through the coleoptile, then these results indicate that the less length the coleoptile is exposed to the herbicide, the less injury will occur.

Wyse et al. (46) in greenhouse and growth chamber studies with navy bean found that soil compaction reduced growth of plants treated with 4.5 kg/ha EPTC. Seed quality also affected thiocarbamate herbicide injury expression (46). Navy bean seeds which were mechanically damaged were more sensitive to EPTC seedling injury than normal seeds. According to Crook (17) soil texture also plays a role in EPTC + R-25788, or butylate + R-25788 corn injury expression. More corn injury occurred on a sandy loam or a loamy sand soil than a silt loam soil. Since there was more corn injury in coarse soils it was thought that R-25788 may be leached or broken down faster than EPTC. In subsequent laboratory studies, R-25788 did not leach or break down faster than EPTC (6,7). In contrast, Thomas and Gray (39) found R-25788 leached faster than EPTC in a loam soil.

Microbial breakdown is the major mechanism by which EPTC, butylate, vernolate and R-25788 are lost from the soil (32,39,41).

Formulation and Herbicidal Properties

Eradicane is a formulation of EPTC plus the antidote R-25788, and is registered for use in sweet, field and silage corn (27,30,41). Butylate is registered for use on sweet or field corn. Sutan+ is a formulation of butylate plus the antidote R-25788 (41). Vernolate is registered for use on soybeans (*Glycine max* L. (Merrill)) peanuts, tobacco (*Nicotiana* spp.), and sweet potatoes (*Ipomoea batatas* L.) Crops tolerant to R-12001 are corn, cotton (*Gossypium* spp.), Irish potatoes (*Solanum tuberosum* L.), peanuts (*Arachis hypogeae* L.), sugar beets (*Beta vulgaris* L.) and sunflower (*Helianthus annus* L.).[2] EPTC, butylate, vernolate, and R-12001 must be incorporated immediately into the soil to a depth of 5-7.5 cm with disc or power-driven rotary tillers. In dry conditions these herbicides can be incorporated with overhead irrigation (41).[3]

Mode of Action

Thiocarbamate herbicides inhibit cell division and elongation, and may alter the GA (gibberellic acid) content of plants (20,30) Thiocarbamate herbicides inhibit meristematic activity in grass roots and

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[2] Anonymous, R-12001 Technical Bulletin, (Stauffer Chemical Co., 1970), pp. 1-3.

[3] Anonymous, 1978 Crop Protection Manual, (Westport, Conn., Stauffer Chemical Co., 1977), pp. 1-146.

shoots, and cause abnormal emergence of leaves from the coleoptile. The leaf margins of many broadleaved plants treated with thiocarbamate herbicides turn up, cupping the leaves (30).

Dawson (18,19) studying the effects of EPTC on barnyardgrass (Echinochloa crusgalli (L.) Beauv.) found that exposing the shoot to EPTC lead to plant injury, but exposing the roots or seeds to EPTC did not lead to plant injury. Dawson (18,19) concluded that leaf tissue is the main site of EPTC injury, and that EPTC at 3 ppmw does not injure barnyardgrass seed prior to germination.

Burt (6) noted two periods in the life cycle of corn when thiocarbamate herbicide injury appears: immediately after corn emergence, and shortly before tasseling. Seedling corn injury symptoms include stunted leaves, which are twisted and appear knotted. Other symptoms include a dark green color and stem brittleness (20). Just before tasseling EPTC causes the corn stalk to twist and bend directly above the ear (6).

Butylate is taken up by the roots of corn plants and translocated throughout the plant. Butylate is metabolized in the roots and leaves to carbon dioxide, diisobutylamine, fatty acids, conjugates of amines and fatty acids, and other natural plant constituents (1,41). Wright and Rieck (44) found that tolerant hybrids took up less ^{14}C-butylate without antidotes, and metabolized more butylate to ^{14}carbon dioxide than butylate-sensitive hybrids.

EPTC is metabolized by plants to carbon dioxide, and other naturally occurring plant constituents (32,41). Nalewaja (35) working with alfalfa (Medicago sativa L.) and ^{14}C labelled EPTC found ^{14}C was incorporated into fructose, glucose and several amino acids.

Vernolate is taken up by roots of soybeans and peanuts, translocated throughout the plant and metabolized to carbon dioxide and other natural plant constituents (1,41).

The actual degradation pathway of thiocarbamate herbicides is still in doubt. Researchers (32) have proposed that the initial step in degradation is hydrolysis of the thioester linkage by soil microbes, plants and animals:

$$R_1\text{-S-}\overset{\overset{\displaystyle O}{\|}}{C}\text{-N}\begin{matrix} \diagup R_2 \\ \diagdown R_3 \end{matrix} \xrightarrow[\text{Hydrolysis}]{H_2O} R_1\text{-SH} + \text{H-N}\begin{matrix} \diagup R_2 \\ \diagdown R_3 \end{matrix} + CO_2$$

After the initial hydrolysis further metabolism may occur.

Other researchers (10,13) believe that under most environmental conditions sulfoxidation is one of the first steps in biodegradation of thiocarbamate herbicides.

$$R_1S\overset{\overset{\displaystyle O}{\|}}{C}N\begin{matrix} \diagup R_2 \\ \diagdown R_3 \end{matrix} \xrightarrow[\text{NADPH}]{\text{Microsomal enzyme}} \underset{\text{Thiocarbamate sulfoxide}}{R_1\overset{\overset{\displaystyle O}{\|}}{S}\overset{\overset{\displaystyle O}{\|}}{C}N\begin{matrix} \diagup R_2 \\ \diagdown R_3 \end{matrix}}$$

$$\xrightarrow[\text{GSH[4]}]{\text{soluble enzyme}} \text{cleavage products}$$

Usually thiocarbamate sulfoxides are more phytotoxic than the corresponding thiocarbamate herbicides, particularly on broadleaf weeds. In greenhouse studies the sulfoxides of butylate, EPTC, and vernolate

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[4]Reduced glutathione.

controlled crabgrass (*Digitaria* spp.), barnyardgrass, and wild oats (*Avena fatua* L.), but crops registered for use with thiocarbamate herbicides were unharmed even at 27 kg/ha of thiocarbamate sulfoxides (13).

The thiocarbamate sulfoxides have several advantages over thiocarbamates as herbicides, including increased crop safety, reduced volatility, and thiocarbamate sulfoxides can be applied to moist soils. The instability and increased leaching of thiocarbamate sulfoxides make them impractical as herbicides. Casida et al. (13) postulated that the improved crop tolerance of thiocarbamate sulfoxides is based on the crop plant's ability to metabolize or detoxify thiocarbamate sulfoxides.

Antidotes for Thiocarbamate Herbicides

Gulf introduced 1,8-naphthalic anhydride (hereafter referred to as NA) in February 1969 as an herbicidal antidote. NA protects corn from herbicidal injury by EPTC, butylate, ethiolate (S-ethyl-diethylthiocarbamate), and vernolate. NA is applied as a seed treatment at a rate of 0.5% by weight of seed corn (40). Researchers (5,24,25,28,29,31,42) have found that NA is an effective antidote preventing or ameliorating EPTC corn injury; also NA is an effective alachlor (2-chloro-2,6-diethyl-N-(methoxymethyl)acetanilide) antidote for sorghum (*Sorghum bicolor* (L.) Moench.) (26,27).

Hickey and Krueger (27) found that sorghum treated with alachlor emerged abnormally from the coleoptile. If primary leaf emergence did occur in the plants treated with alachlor, it occurred along the sides of the coleoptile. Plants treated with alachlor plus NA, or without alachlor normal leaf emergence occurred through the coleoptile tip.

In a separate study Hickey and Krueger (28) described abnormal emergence from the coleoptile of corn when treated with alachlor, which is similar to corn leaf emergence treated with EPTC. They found that twice as much force was required to induce leaf slippage from the coleoptile of corn treated with 25 ppmw alachlor, as compared with the control. When corn was treated with NA and alachlor, the force required to induce leaf slippage was not different from the controls.

Donald et al. (20,21) found that GA_3 applied to EPTC treated corn prevented corn injury, and enhanced stem growth.

Stauffer Chemical Company has developed antidotes that prevent or ameliorate thiocarbamate herbicide corn injury. The antidote R-25788 was developed in 1970, and is commercially available in formulations with EPTC, and butylate (27,30,41); R-29148 is an experimental antidote also used in formulations with thiocarbamate herbicides.

Chang et al. (16) found that R-25788 is an effective antidote for EPTC and barban (4-chloro-2-butynyl m-chlorocarbanilate). R-25788 is intermediate in effectiveness as an antidote for vernolate, molinate (S-ethyl hexahydro-1H-azepine-1-carbothioate), butylate, alachlor and pebulate (S-propyl butylethylthiocarbamate); but had little effect on linuron (3-(3,4-dichlorophenyl)-1-methoxy-1-methyl urea), and diallate (S-(2,3-dichloroallyl) diisopropylthiocarbamate). R-25788 also gave limited protection to sorghum treated with low rates of EPTC. The antidote R-25788 is also effective as a seed treatment from 0.5%-1% of the seed corn weight (14,15).

Donald and Fawcett (20) found R-29148 to be an effective EPTC antidote up to three days after planting if applied as a soil drench at 0.56 kg/ha.

Lay et al. (34) found R-25788 and R-29148 increased glutathione levels in corn roots, and increased oxidation of EPTC within the plant to form EPTC sulfoxide. Reduced glutathione then reacts with EPTC sulfoxide forming a conjugate. R-29148 and R-25788 increased the activity levels of the enzyme glutathione-S-transferase which is a catalyst in sulfoxide cleavage. Carringer et al. (11) in contrast did not find increased activity levels of glutathione-S-transferase. Carringer and Rieck (9) found that R-25788 stimulated the breakdown of EPTC to water soluble products.

Carringer et al. (9) in a study with five corn inbreds found that 0.4 and 0.8 ppmw of R-25788 or R-29148 reduced the fresh and dry weights of all the inbreds; and antidotes plus EPTC or butylate reduced the fresh and dry weights of four of the inbreds.

Crook (17) found that EPTC + R-25788 caused more corn injury than did butylate + R-25788. Also some corn hybrids are injured more often than other hybrids; susceptible hybrids are not always injured, and thiocarbamate herbicide tolerant hybrids are occasionally injured. According to Donald et al. (21) once seedling injury has occurred neither R-25788 nor R-29148 reverse injury symptoms, thus these antidotes prevent injury but do not reverse injury symptoms.

CHAPTER III

MATERIALS AND METHODS

Experiments were conducted during 1977 at three Tennessee locations: the West Tennessee Experiment Station, Jackson; Milan Field Station, Milan; and the Plant Science Field Laboratory, Knoxville. Nine corn hybrids selected for thiocarbamate herbicide response in 1976 were used in this study. The nine hybrids were DeKalb XL55, McNair X210, Pioneer brand 3368A, Funk G4507, P.A.G. 644W, DeKalb XL72B, Pioneer brand 3369A, Pioneer brand 3147, and McNair X300. The Jackson test was primarily a study of susceptibility of the hybrids to thiocarbamate injury at the 4.5 kg/ha rate, and the maximum label rate, 6.9 kg/ha of butylate + R-25788 and EPTC + R-25788. At Milan the antidotes R-29148 and R-25788 in formulations with butylate and EPTC were evaluated. The Knoxville study involved the use of vernolate with both antidotes, EPTC + R-25788 and R-12001 + R-25788. The entire test area received a uniform application of 2.2 kg/ha atrazine as a permergence application at all locations.

The experimental design was a split block within a randomized complete block with four replications at Jackson and Milan, and six replications at Knoxville. All tests were hand hoed or mechanically cultivated as needed for weed control. Throughout the growing season data were obtained on corn injury expressed in terms of wrinkled or folded leaves, bent stalks, deformed ears, incomplete husk cover or deformed husks, increased tillering, smut occurrence, and reduced grain yield. Comparisons between treatments were made using Duncan's new multiple range test at the 5% level (3).

Milan Test

On March 16, 1977, fertilizer was broadcast at a rate of 157 kg/ha of nitrogen, 59 kg/ha of phosphorus, 112 kg/ha of potassium, 1 kg/ha of boron and 6 kg/ha of zinc. The test area was disced on March 16 and chiselled on March 18. Herbicides were applied March 29 at a rate of 4.5 kg/ha. The herbicides were incorporated with a tandem disc operated across the plots, and with a do-all cultivator operated in the row direction. The herbicides in this study were EPTC + R-25788 (Eradicane), EPTC + R-29148, butylate + R-25788 (Sutan+), and butylate + R-29148. Fifty corn seeds were planted/row on April 11, 1977; each plot consisted of two rows, 9.15 meters long, with a one meter row spacing, on a Falaya silt loam soil.

Seedling injury counts were made May 10. The plots were thinned to 44 plants/9.15 meter row on May 17, giving a population of 47,400 plants/ha. Corn injury counts caused by thiocarbamate herbicides were made (just before tasseling) on June 1, and (just after tasseling) on June 14. The number of tillers and occurrence of smut infestation were counted on July 15. On September 22, the plots were harvested with a combine-picker-sheller; and grain yields adjusted to 15.5% moisture.

Jackson Test

Fertilizer was broadcast at a rate of 40 kg/ha of nitrogen, 25 kg/ha of phosphorus, and 25 kg/ha of potassium on March 15, 1977, and fertilized again on March 17 at a rate of 147 kg/ha of nitrogen, 63 kg/ha of phosphorus and 63 kg/ha of potassium, giving a total fertilizer rate of 187 kg/ha of nitrogen, 87 kg/ha of phosphorus, and 87 kg/ha of potassium. On April 19, the herbicides butylate + R-25788 and EPTC + R-25788 were applied at 4.5 kg/ha, and 6.9 kg/ha on a smooth seed bed, and immediately disc incorporated followed by a do-all cultivator to smooth the soil. The controls were also disced and do-alled. The corn was planted on April 20, fifty seeds/9.15 meter row, with a one meter row spacing on a Grenada or Callaway silt loam soil. Carbofuran was applied for insect control in the furrow at the rate of 1.7 kg/ha.

Seedling injury counts were made on May 10. The plots were sized to 7.6 meters and thinned to thirty-three plants/row on May 18-20. Injured plant counts were made on June 1 (just before tasseling) and June 14 (just after tasseling). The number of tillers and occurrence of smut infestation counts were made on July 15. Corn was harvested by hand on September 9 and shelled with a stationary combine. Grain yields were adjusted to 15.5% moisture.

Knoxville Test

Fertilizer rates of 67 kg/ha of nitrogen, 112 kg/ha of phosphorus, and 59 kg/ha of potassium were broadcast prior to herbicide application. Herbicides were applied at 4.5 kg/ha April 19, 1977, and immediately incorporated with a roto tiller. The herbicides in this study were R-12001 + R-25788, vernolate + R-25788, vernolate + R-29148, and

EPTC + R-25788. The hybrids were planted April 20, twenty-five seeds/ 3 meter row. Each plot was two rows wide. Row spacing was one meter. The experiment was established on an Etowah clay loam. The number of injured seedlings were counted on May 16. The plots were thinned to twenty-three plants per row, giving a population of 53,000 plants/ha. On June 6 the plots were sidedressed with 60 kg/ha of nitrogen (ammonium nitrate). Subsequent corn injury counts were made on June 7 (just prior to tasseling) and June 30 (just after tasseling). The number of hermaphroditic flowers (tassel ears), and smut occurrence, were recorded on July 11, and on July 12 tiller counts were made. On September 19 and September 20 the plots were harvested by hand. Grain yields were adjusted to 15.5% moisture.

CHAPTER IV

RESULTS

Milan Test

Injury counts were taken on May 10 (Table 3), June 1 (Table 4) and June 14 (Table 5). EPTC + R-25788 (4.5 kg/ha) caused some plant injury to DeKalb XL55 on all dates. DeKalb XL55 became infested with smut when treated with EPTC + R-25788 (Table 6). Increased tillering occurred when DeKalb XL55 was treated with EPTC + R-25788 at 4.5 kg/ha (Table 7).

Pioneer brand 3147 treated with butylate + R-25788 produced grain yields greater than its control (Table 8). The yield of McNair X300, Funk G4507 and McNair X210 were reduced by the EPTC + R-29148 treatment. The corn grain yield of DeKalb XL72B, Pioneer brand 3369A, Pioneer brand 3368A, McNair X300, and Funk G4507 were reduced by butylate + R-29148. Butylate + R-25788 did not reduce the yields of any hybrid.

Jackson Test

DeKalb XL55 seedlings were injured when treated with 4.5 kg/ha or 6.9 kg/ha EPTC + R-25788. These plants exhibited typical thiocarbamate injury symptoms when counts were made on May 10 (Table 9). Most of these plants did not recover and a similar pattern of injury was revealed in the injury counts made June 1 (Table 10). DeKalb XL55 was injured when treated with EPTC + R-25788 at 4.5 or 6.9 kg/ha. DeKalb XL55 was also injured with butylate + R-25788 at 6.9 kg/ha. On June 14 (Table 11) EPTC + R-25788 at both rates injured DeKalb XL55, but few

Table 3

CORN SEEDLING INJURY COUNTS AT MILAN[abcd]

Hybrids	Number of Injured Plants per Plot				
	Control	EPTC + R-25788	EPTC + R-29148	Butylate + R-25788	Butylate + R-29148
DeKalb XL55	0 b	89 a	0 b	0 b	0 b
McNair X210	1 a	0 a	1 a	1 a	1 a
Pioneer brand 3368A	0 a	0 a	2 a	0 a	0 a
Funk G4507	1 a	2 a	1 a	1 a	1 a
P.A.G. 644W	1 a	1 a	1 a	1 a	1 a
DeKalb XL72B	1 a	4 a	1 a	1 a	2 a
Pioneer brand 3369A	1 a	1 a	1 a	1 a	1 a
Pioneer brand 3147	0 a	1 a	1 a	1 a	1 a
McNair X300	1 a	0 a	2 a	1 a	1 a

[a]Injured plants were counted May 10, 29 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range rest.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

[d]All thiocarbamate herbicides were applied at 4.5 kg/ha.

Table 4

CORN PLANT INJURY COUNTS TAKEN JUST BEFORE TASSELING AT MILAN[abcd]

Hybrids	Number of Injured Plants per Plot				
	Control	EPTC + R-25788	EPTC + R-29148	Butylate + R-25788	Butylate + R-29148
DeKalb XL55	1 b	69 a	1 b	1 b	1 b
McNair X210	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3368A	0 a	0 a	0 a	0 a	0 a
Funk G4507	0 a	0 a	0 a	0 a	0 a
P.A.G. 644W	0 a	0 a	1 a	0 a	0 a
DeKalb XL72B	0 a	1 a	1 a	0 a	1 a
Pioneer brand 3369A	0 a	0 a	0 a	0 a	1 a
Pioneer brand 3147	0 a	0 a	0 a	0 a	1 a
McNair X300	0 a	0 a	1 a	0 a	1 a

[a]Injured plants were counted June 1, 51 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

[d]All thiocarbamate herbicides were applied at 4.5 kg/ha.

Table 5

CORN PLANT INJURY COUNTS TAKEN JUST AFTER TASSELING AT MILAN[abcd]

Hybrids	Number of Injured Plants per Plot				
	Control	EPTC + R-25788	EPTC + R-29148	Butylate + R-25788	Butylate + R-29148
DeKalb XL55	0 b	77 a	0 b	0 b	1 b
McNair X210	1 a	1 a	1 a	1 a	1 a
Pioneer brand 3368A	0 a	2 a	0 a	0 a	0 a
Funk G4507	0 a	0 a	0 a	0 a	0 a
P.A.G. 644W	0 a	0 a	0 a	0 a	0 a
DeKalb XL72B	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3369A	0 a	0 a	0 a	0 a	1 a
Pioneer brand 3147	0 a	0 a	0 a	0 a	0 a
McNair X300	0 a	0 a	0 a	0 a	0 a

[a]Injured plants were counted June 14, 65 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

[d]All thiocarbamate herbicides were applied at 4.5 kg/ha.

Table 6

CORN SMUT INFESTATION COUNTS AT MILAN[abcd]

Hybrids	Number of Smut Infested Plants per Plot				
	Control	EPTC + R-25788	EPTC + R-29148	Butylate + R-25788	Butylate + R-29148
DeKalb XL55	0 b	19 a	0 b	0 b	0 b
McNair X210	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3368A	0 a	0 a	0 a	0 a	0 a
Funk G4507	0 a	0 a	0 a	0 a	0 a
P.A.G. 644W	1 a	0 a	0 a	0 a	0 a
DeKalb XL72B	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3369A	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3147	0 a	0 a	0 a	0 a	0 a
McNair X300	0 a	0 a	0 a	0 a	0 a

[a]Smut infestation counts were made July 15, 96 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

[d]All thiocarbamate herbicides were applied at 4.5 kg/ha.

Table 7

CORN TILLER COUNTS AT MILAN[abcd]

Hybrids	Number of Tillers per Plot				
	Control	EPTC + R-25788	EPTC + R-29148	Butylate + R-25788	Butylate + R-29148
DeKalb XL55	3 b	117 a	2 b	5 b	2 b
McNair X210	1 a	1 a	1 a	1 a	1 a
Pioneer brand 3368A	1 a	1 a	0 a	1 a	1 a
Funk G4507	2 a	4 a	4 a	4 a	5 a
P.A.G. 644W	6 a	7 a	8 a	8 a	6 a
DeKalb XL72B	4 a	7 a	7 a	5 a	5 a
Pioneer brand 3369A	1 a	1 a	3 a	2 a	1 a
Pioneer brand 3147	3 a	4 a	2 a	4 a	2 a
McNair X300	7 a	8 a	8 a	10 a	9 a

[a]Corn tiller counts were made July 15, 96 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

[d]All thiocarbamate herbicides were applied at 4.5 kg/ha.

Table 8

CORN GRAIN YIELDS AT MILAN[ab]

Hybrids	Corn Grain Yields kg/ha				
	Control	EPTC + R-25788	EPTC + R-29148	Butylate + R-25788	Butylate + R-29148
DeKalb XL55	8727 a	4668 b	8186 a	8253 a	7847 a
McNair X210	8591 a	8186 ab	7442 b	9133 a	8186 ab
Pioneer brand 3368A	9539 a	8930 ab	8524 ab	9403 ab	8456 b
Funk G4507	9336 a	8862 ab	8253 b	8456 ab	8118 b
P.A.G. 644W	8862 a	8118 a	7847 a	8118 a	8186 a
DeKalb XL72B	8794 a	8659 ab	8727 ab	8659 ab	7712 b
Pioneer brand 3369A	9539 a	9539 a	9471 a	9877 a	7847 b
Pioneer brand 3147	10215 b	10486 ab	10283 ab	11230 a	9539 b
McNair X300	8862 a	8591 abc	7780 bc	8794 ab	7644 c

[a]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[b]All thiocarbamate herbicides were applied at 4.5 kg/ha.

Table 9

CORN SEEDLING INJURY COUNTS AT JACKSON[abc]

Hybrids	Number of Injured Plants per Plot				
	Control	EPTC + R-25788		Butylate + R-25788	
		4.5 kb/ha	6.9 kg/ha	4.5 kb/ha	6.9 kg/ha
DeKalb XL55	0 b	65 a	63 a	1 b	1 b
McNair X210	0 a	0 a	0 a	1 a	1 a
Pioneer brand 3368A	0 a	0 a	1 a	0 a	0 a
Funk G4507	0 a	0 a	2 a	0 a	1 a
P.A.G. 644W	0 a	0 a	1 a	0 a	0 a
DeKalb XL72B	1 a	3 a	3 a	0 a	0 a
Pioneer brand 3369A	0 a	1 a	1 a	0 a	0 a
Pioneer brand 3147	2 a	0 a	2 a	1 a	1 a
McNair X300	0 a	0 a	1 a	0 a	1 a

[a]Injured plant counts were made May 10, 20 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

Table 10

CORN PLANT INJURY COUNTS JUST PRIOR TO TASSELING AT JACKSON[abc]

Hybrids	Number of Injured Plants per Plot				
	Control	EPTC + R-25788		Butylate + R-25788	
		4.5 kg/ha	6.9 kg/ha	4.5 kg/ha	6.9 kg/ha
DeKalb XL55	0 c	37 a	43 a	2 c	13 b
McNair X210	1 a	3 a	4 a	1 a	1 a
Pioneer brand 3368A	0 a	0 a	1 a	1 a	0 a
Funk G4507	0 a	0 a	1 a	0 a	0 a
P.A.G. 644W	0 a	0 a	1 a	0 a	0 a
DeKalb XL72B	0 a	0 a	1 a	0 a	0 a
Pioneer brand 3369A	0 a	1 a	0 a	0 a	0 a
Pioneer brand 3147	0 a	0 a	1 a	1 a	0 a
McNair X300	0 a	0 a	1 a	0 a	1 a

[a]Injured plant counts were made June 1, 42 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

Table 11

CORN PLANT INJURY COUNTS JUST AFTER TASSELING AT JACKSON[abc]

Hybrids	Number of Injured Plants per Plot				
		EPTC + R-25788		Butylate + R-25788	
	Control	4.5 kg/ha	6.9 kg/ha	4.5 kg/ha	6.9 kg/ha
DeKalb XL55	0 b	53 a	50 a	0 b	0 b
McNair X210	0 a	1 a	2 a	0 a	0 a
Pioneer brand 3368A	0 a	0 a	0 a	0 a	0 a
Funk G4507	0 a	0 a	0 a	0 a	0 a
P.A.G. 644W	0 a	0 a	0 a	0 a	0 a
DeKalb XL72B	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3369A	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3147	0 a	0 a	0 a	0 a	0 a
McNair X300	0 a	0 a	0 a	0 a	0 a

[a]Injured plant counts were made June 14, 56 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

injured plants were found among other hybrids. Smut infestation (Table 12) and increased tillering (Table 13) was associated with DeKalb XL55 when treated with EPTC + R-25788 at 4.5 or 6.9 kg/ha on July 15.

The final data obtained were corn grain yields (Table 14). The yield of P.A.G. 644W, DeKalb XL72B and Pioneer brand 3369A increased over the control when treated with 6.9 kg/ha of butylate + R-25788. The grain yield of McNair X210 increased over its control when treated with butylate + R-25788 at 4.5 kg/ha. The yield of DeKalb XL55 was reduced when treated with EPTC + R-25788 at 4.5 or 6.9 kg/ha.

Knoxville Test

DeKalb XL55 seedlings were injured (Table 15) when treated with EPTC + R-25788 or vernolate + R-29148 at 4.5 kg/ha. On June 7 (Table 16) and June 30 (Table 17) DeKalb XL55 was the only hybrid which showed significant thiocarbamate injury.

DeKalb XL55 treated with either EPTC + R-25788, or vernolate + R-29148, became smut infested (Table 18). DeKalb XL55 treated with either EPTC + R-25788, or vernolate + R-29148 had an increased incidence of tillering (Table 19). Hermaphroditic flowers (Table 20) were counted July 11, DeKalb XL55 was the only hybrid to show this injury symptom. This injury occurred in plots treated with vernolate + R-29148 or EPTC + R-25788.

The corn grain yield (Table 21) of Pioneer brand 3147 was reduced by R-12001 + R-25788. Vernolate + R-25788 decreased the yield of McNair X210, P.A.G. 644W, Pioneer brand 3147, and Pioneer brand 3369A,

Table 12

CORN SMUT INFESTATION COUNTS AT JACKSON[abc]

Hybrids	Number of Smut Infested Plants per Plot				
	Control	EPTC + R-25788		Butylate + R-25788	
		4.5 kg/ha	6.9 kg/ha	4.5 kg/ha	6.9 kg/ha
DeKalb XL55	2 b	11 a	9 a	2 b	3 b
McNair X210	0 a	1 a	1 a	0 a	0 a
Pioneer brand 3368A	0 a	1 a	0 a	0 a	0 a
Funk G4507	2 a	2 a	2 a	2 a	1 a
P.A.G. 644W	1 a	0 a	0 a	1 a	0 a
DeKalb XL72B	1 a	0 a	0 a	1 a	0 a
Pioneer brand 3369A	1 a	1 a	2 a	0 a	0 a
Pioneer brand 3147	0 a	0 a	0 a	0 a	0 a
McNair X300	1 a	1 a	1 a	0 a	1 a

[a]Smut infestation counts were made July 15, 87 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

Table 13

CORN TILLER COUNTS AT JACKSON[abc]

Hybrids	Number of Tillers per Plot				
	Control	EPTC + R-25788		Butylate + R-25788	
		4.5 kg/ha	6.9 kg/ha	4.5 kg/ha	6.9 kg/ha
DeKalb XL55	17 b	64 a	67 a	19 b	16 b
McNair X210	11 a	13 a	12 a	13 a	14 a
Pioneer brand 3368A	7 a	5 a	5 a	6 a	6 a
Funk G4507	14 a	21 a	16 a	12 a	11 a
P.A.G. 644W	22 a	35 a	29 a	22 a	31 a
DeKalb XL72B	17 a	14 a	14 a	11 a	14 a
Pioneer brand 3369A	5 a	9 a	10 a	6 a	8 a
Pioneer brand 3147	11 a	15 a	12 a	15 a	13 a
McNair X300	10 a	10 a	11 a	13 a	11 a

[a]Corn tiller counts were made July 15, 87 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

Table 14

CORN GRAIN YIELDS AT JACKSON[a]

Hybrids	Corn Grain Yields kg/ha				
		EPTC + R-25788		Butylate + R-25788	
	Control	4.5 kg/ha	6.9 kg/ha	4.5 kg/ha	6.9 kg/ha
DeKalb XL55	5277 a	3247 b	2841 b	6021 a	6156 a
McNair X210	5683 b	6107 ab	6089 ab	7374 a	6427 ab
Pioneer brand 3368A	6223 a	7374 a	6562 a	7239 a	7509 a
Funk G4507	6765 ab	6833 ab	6156 b	7509 a	7171 ab
P.A.G. 644W	5412 b	5818 ab	6156 ab	6021 ab	6833 a
DeKalb XL72B	5547 b	6697 ab	5953 ab	6359 ab	6900 a
Pioneer brand 3369A	6697 b	7780 ab	6968 ab	7509 ab	8186 a
Pioneer brand 3147	6697 a	7103 a	6107 a	7036 a	7509 a
McNair X300	6900 ab	7171 ab	6156 b	7374 ab	7712 a

[a]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

Table 15

CORN SEEDLING INJURY COUNTS AT KNOXVILLE[abcd]

Hybrids	Number of Injured Plants per Plot				
	Control	R-12001 + R-25788	Vernolate + R-25788	Vernolate + R-29148	EPTC + R-25788
DeKalb XL55	0 b	0 b	0 b	41 a	45 a
McNair X210	1 a	6 a	7 a	2 a	1 a
Pioneer brand 3368A	0 a	0 a	1 a	0 a	0 a
Funk G4507	0 a	1 a	0 a	1 a	0 a
P.A.G. 644W	0 a	2 a	2 a	1 a	1 a
DeKalb XL72B	0 a	0 a	1 a	2 a	3 a
Pioneer brand 3369A	0 a	0 a	2 a	1 a	0 a
Pioneer brand 3147	0 a	1 a	1 a	1 a	1 a
McNair X300	0 a	1 a	0 a	1 a	1 a

[a]Injured plants were counted May 16, 26 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

[d]All thiocarbamate herbicides were applied at 4.5 kg/ha.

Table 16

CORN PLANT INJURY COUNTS JUST PRIOR TO TASSELING AT KNOXVILLE[abcd]

Hybrids	Number of Injured Plants per Plot				
	Control	R-12001 + R-25788	Vernolate + R-25788	Vernolate + R-29148	EPTC + R-25788
DeKalb XL55	0 b	0 b	0 b	38 a	41 a
McNair X210	0 a	0 a	0 a	1 a	0 a
Pioneer brand 3368A	0 a	0 a	0 a	0 a	0 a
Funk G4507	0 a	0 a	1 a	0 a	0 a
P.A.G. 644W	0 a	0 a	0 a	0 a	0 a
DeKalb XL72B	0 a	0 a	0 a	1 a	0 a
Pioneer brand 3369A	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3147	0 a	0 a	1 a	0 a	0 a
McNair X300	1 a	0 a	0 a	0 a	0 a

[a]Injured plants were counted June 7, 48 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

[d]All thiocarbamate herbicides were applied at 4.5 kg/ha.

Table 17

CORN PLANT INJURY COUNTS TAKEN JUST AFTER TASSELING AT KNOXVILLE[abcd]

Hybrids	Number of Injured Plants per Plot				
	Control	R-12001 + R-25788	Vernolate + R-25788	Vernolate + R-29148	EPTC + R-25788
DeKalb XL55	0 b	0 b	0 b	32 a	36 a
McNair X210	0 a	0 a	0 a	0 a	2 a
Pioneer brand 3368A	0 a	0 a	0 a	5 a	0 a
Funk G4507	0 a	0 a	0 a	0 a	0 a
P.A.G. 644W	0 a	0 a	0 a	0 a	0 a
DeKalb XL72B	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3369A	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3147	0 a	0 a	0 a	0 a	0 a
McNair X300	0 a	0 a	0 a	0 a	0 a

[a]Injured plants were counted June 30, 71 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

[d]All thiocarbamate herbicides were applied at 4.5 kg/ha.

Table 18

CORN SMUT INFESTATION COUNTS AT KNOXVILLE[abcd]

Hybrids	Number of Smut Infested Plants per Plot				
	Control	R-12001 + R-25788	Vernolate + R-25788	Vernolate + R-29148	EPTC + R-25788
DeKalb XL55	0 b	0 b	0 b	5 a	9 a
McNair X210	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3368A	0 a	0 a	0 a	0 a	0 a
Funk G4507	0 a	0 a	0 a	0 a	0 a
P.A.G. 644W	0 a	0 a	0 a	0 a	0 a
DeKalb XL72B	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3369A	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3147	0 a	0 a	0 a	0 a	0 a
McNair X300	0 a	0 a	0 a	0 a	0 a

[a]Smut infestation counts were made July 11, 82 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

[d]All thiocarbamate herbicides were applied at 4.5 kg/ha.

Table 19

CORN TILLER COUNTS AT KNOXVILLE[abcd]

Hybrids	Number of Tillers per Plot				
	Control	R-12001 + R-25788	Vernolate + R-25788	Vernolate + R-29148	EPTC + R-25788
DeKalb XL55	3 c	4 c	4 c	59 b	73 a
McNair X210	0 a	1 a	1 a	1 a	1 a
Pioneer brand 3368A	1 a	1 a	2 a	1 a	1 a
Funk G4507	0 a	0 a	1 a	0 a	0 a
P.A.G. 644W	0 a	0 a	0 a	0 a	0 a
DeKalb XL72B	4 a	3 a	3 a	4 a	4 a
Pioneer brand 3369A	2 a	2 a	3 a	2 a	2 a
Pioneer brand 3147	0 a	0 a	1 a	0 a	0 a
McNair X300	7 a	6 a	6 a	6 a	8 a

[a]Corn tillers were counted on July 12, 83 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

[d]All thiocarbamate herbicides were applied at 4.5 kg/ha.

Table 20

HERMAPHRODITIC FLOWER COUNT AT KNOXVILLE[abcd]

Hybrids	Number of Hermaphroditic Flowers per Plot				
	Control	R-12001 + R-25788	Vernolate + R-25788	Vernolate + R-29148	EPTC + R-25788
DeKalb XL55	0 b	0 b	0 b	19 a	23 a
MCNair X210	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3368A	0 a	0 a	0 a	0 a	0 a
Funk G4507	0 a	0 a	0 a	0 a	0 a
P.A.G. 644W	0 a	0 a	0 a	0 a	0 a
DeKalb XL72B	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3369A	0 a	0 a	0 a	0 a	0 a
Pioneer brand 3147	0 a	0 a	0 a	0 a	0 a
McNair X300	0 a	0 a	0 a	0 a	0 a

[a]Hermaphroditic flower counts were made July 11, 82 days after planting.

[b]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[c]This data was transformed using $\sqrt{X} + \sqrt{X + 1}$ to facilitate statistical analysis.

[d]All thiocarbamate herbicides were applied at 4.5 kg/ha.

Table 21

CORN GRAIN YIELDS AT KNOXVILLE[ab]

Hybrids	Corn Grain Yields kg/ha				
	Control	R-12001 + R-25788	Vernolate + R-25788	Vernolate + R-29148	EPTC + R-25788
DeKalb XL55	7915 a	7239 a	6968 a	5277 b	4059 b
McNair X210	8794 a	7712 ab	7442 b	8050 ab	8253 ab
Pioneer brand 3368A	8997 a	8930 a	7847 a	8524 a	8592 a
Funk G4507	7780 a	7577 a	7239 a	7644 a	7780 a
P.A.G. 644W	8456 a	7577 ab	6765 b	7171 b	7847 ab
DeKalb XL72B	7780 a	7644 a	7027 a	7239 a	6968 a
Pioneer brand 3369A	9336 a	8591 ab	7780 b	8862 ab	8659 ab
Pioneer brand 3147	9674 a	8321 bc	8253 c	8591 abc	8794 ab
McNair X300	9133 a	8727 a	8118 a	8794 a	9133 a

[a]Numbers followed by the same letter in the same row are not significantly different at the 5% level using Duncan's new multiple range test.

[b]All thiocarbamate herbicides were applied at 4.5 kg/ha.

while vernolate + R-29148 decreased the yield of DeKalb XL55 and P.A.G. 644W. EPTC + R-25788 reduced the grain yield of DeKalb XL55.

CHAPTER V

DISCUSSION

The most obvious effect of thiocarbamate herbicides on corn during seedling stages of growth at all locations was the injury to DeKalb XL55, when treated with EPTC + R-25788. At Knoxville, DeKalb XL55 was also severely injured by vernolate + R-29148. In these situations the leaves did not unfold and remained tightly rolled within the first leaf. Elongation of the plants was inhibited with the primary shoot frequently dying, or being severely deformed. Some of these plants developed normal-appearing tillers which quickly replaced the primary shoot.

Pfund and Crum (36) of DeKalb AgResearch have indicated the existence of a dominant gene in the inbred corn line H4101 that determines susceptibility to EPTC + R-25788. It is presumed that this gene is present in DeKalb XL55, and is the genetic nature of the extreme susceptibility of this hybrid to EPTC + R-25788. In contrast DeKalb XL55 was not damaged by vernolate + R-25788, R-12001 + R-25788, EPTC + R-29148, or butylate with either antidote. R-29148 was an effective antidote for EPTC but not for vernolate, whereas R-25788 was an effective antidote for vernolate but not for EPTC when DeKalb XL55 was the indicator hybrid. Both the antidotes and the herbicides have structural similarities; therefore, it would seem that the effectiveness of the antidotes may be dependent upon rather subtle differences in the chemical structure. If it is assumed that enzyme activities are being affected by these antidotes, either the attachment sites for vernolate and EPTC antidotal effects are different, or different enzymes are being affected. An interesting possibility is presented when it is considered that GA may prevent EPTC injury in corn (20,26). Does R-25788 affect the same site as GA or is a GA stimulated enzyme being affected by R-25788? If the latter is so then why the disparity between the antidotal effects for the herbicides vernolate and EPTC? These are interesting areas for further research. Use of a single hybrid that is damaged by both vernolate and EPTC and the availability of effective antidotes for both herbicides could be valuable tools both in investigating the effects of the antidotes and perhaps in more clearly defining the mechanism of action of thiocarbamate herbicides. The glutathione transferase activity (34) and the effects of thiocarbamates on lipid biosynthesis (43) would be interesting areas in which to start a research project.

The other hybrids in the study were not so uniformly injured by any chemical treatment, with only a portion of the plants showing thiocarbamate injury symptoms in the seedling stages. Although the vulnerability of these hybrids probably has a genetic basis, it would seem that it could not be the dominant gene heritability present in DeKalb XL55, because of this sporadic injury. Perhaps it is a more quantitative type of inheritance. Frequently, the injury symptoms observed were not severe. It was not unusual for the plants to recover and make near-normal growth after having symptoms of thiocarbamate herbicide injury involving deformations of one or more leaves.

The injury symptoms observed in small numbers among some of the hybrids may be due to either genetic variation or variation in the microenvironment. All hybrids studied were single cross, or modified single cross, except for P.A.G. 644W and Pioneer brand 3368A which were three way crosses. A three way cross should have more genetic variability than single crosses (22,23).

Differences in the microenvironment could include moisture variation around the seeds. Thiocarbamate herbicides are easily volatilized from moist soils (41). Since thiocarbamates are active in the vapor phase (1), thiocarbamate vapor in the soil air could cause plant injury. Moisture could also seal thiocarbamate vapors in the soil air around a particular plant causing injury. Large amounts of moisture in soil decrease air space and therefore could concentrate herbicide vapors in the soil.

Wyse (46) studying the effects of environmental factors affecting the phytotoxicity of EPTC to navy beans found that moisture content of the soil one of the most important factors affecting crop injury. Compaction of the soil has also been shown to increase phytotoxicity of the thiocarbamate herbicides (46). Compaction also would decrease soil aeration and hinder the escape of volatile herbicides to the atmosphere. The aspiration of herbicide vapor from the immediate vicinity of the corn seed and the emerging coleoptile could affect the concentration of herbicide in the immediate vicinity of susceptible tissues. Variations in planting depth and seed placement also affect thiocarbamate injury (7). The further the coleoptile must penetrate through treated soil the more likely injury will occur. Thorough incorporation is required to prevent thiocarbamate injury (7). The power driven rototiller used in incorporating these herbicides would be expected to give a very thorough incorporation.[5] Therefore, incorporation should not be a factor in the expression of herbicide injury symptoms. Damaged seed was more susceptible to EPTC injury in the studies with navy bean (46). Damaged seed may explain why some plants showed apparent thiocarbamate herbicide injury, even in the control plots.

Very little of the late season injury described by Burt (6), such as bending of the stalk above the ear, was noted in these experiments. This may have been due to favorable environment conditions during this stage of growth. Differential leaching (39) does not in my opinion explain corn injury caused by thiocarbamate herbicides. These herbicides have a half-life of one to three weeks under normal growing conditions (41). Before any late season symptoms would appear the herbicide would be dissipated or nearly dissipated in the soil, so any late season thiocarbamate injury symptoms would have been a result of herbicide damage during earlier stages of corn development.

Tillering by DeKalb XL55 when treated by EPTC + R-25788 or vernolate + R-29148 was a result of the severe damage or death of the growing point. Tillering by DeKalb XL55 also may have been a result of disruption of the gibberlic acid balance within the plant. According to Beard (2) exogenous GA reduces the amount of tillering in turf grasses. Researchers (20,26) have also found that GA is an effective

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[5]Anonymous, 1978 Crop protection manual, (Westport, Conn., Stauffer Chemical Co., 1977), pp. 1-146.

antidote for EPTC or alachlor in corn. If thiocarbamate herbicides do reduce the amount of GA in corn, tillering could be expected.

The severe smut infestation exhibited by DeKalb XL55 when treated with vernolate + R-29148 or EPTC + R-25788 was a secondary treatment effect caused by the leaf and husk cover deformations. These deformations allowed moisture to be trapped providing a favorable environment (33) for the smut spores to germinate.

The total of all growth during the growing season affects yield. The seedling injury of DeKalb XL55 when treated with EPTC + R-25788 or vernolate + R-29148 ultimately resulted in yield reductions. Yield reductions were not consistent with plant injury during the growing season in the other hybrids, although several hybrids did have reduced grain yields following some herbicide treatments. The yields of three hybrids were reduced when treated with EPTC + R-29148, and the yields of five hybrids were reduced when treated with butylate + R-29148 (Table 8, page 24). Vernolate + R-29148 reduced the yield of four hybrids, while vernolate + R-25788 reduced the yield of two hybrids (Table 21, page 38). No indication of plant injury was observed before the grain yields were obtained from these hybrids. If thiocarbamate herbicides are taken up through the coleoptile (7,18), some insidious damage may have occurred which was not apparent until corn grain yields were determined.

Yield increases (Table 14, page 31) which were barely significant were probably due to good weed control, coupled with the less damaging effects of butylate (17).

CHAPTER VI

SUMMARY AND CONCLUSIONS

Milan Test

During the growing season the experimental antidote R-29148 did appear to be superior as a thiocarbamate-corn antidote to the commercial antidote R-25788 in combinations with EPTC or butylate. None of the hybrids tested showed thiocarbamate injury symptoms when the antidote was R-29148. Though a very susceptible hybrid (DeKalb XL55) was protected by R-29148; when the corn grain yields (Table 8, page 24) were calculated it was found that R-29148 was not superior to R-25788. Six of the nine hybrids tested showed a yield reduction when the antidote was R-29148. Even butylate which is normally less damaging to corn than the other thiocarbamates (17) caused some yield reductions when the antidote was R-29148. In this study the experimental antidote R-29148 was not found to be superior to the commercial antidote R-25788 in combination with butylate or EPTC.

Jackson Test

EPTC + R-25788 at 4.5 or 6.9 kg/ha consistently injured DeKalb XL55 (Tables 9, page 25; 10, page 26; 11, page 27; 12, page 29; 13, page 30; 14, page 31). Butylate + R-25788 at 6.9 kg/ha on June 1 (Table 10, page 26) also injured DeKalb XL55.

The only yield reduction observed was DeKalb XL55 treated with EPTC + R-25788 at 4.5 or 6.9 kg/ha (Table 14, page 31). Probably this reduction was a result of continuing damage caused by this herbicide throughout the growing season. Four hybrids showed increased yield when treated with butylate + R-25788. The grain yield of McNair X210 was increased when treated with butylate + R-25788 at 4.5 kg/ha, and the grain yields of P.A.G. 644W, DeKalb XL72B, and Pioneer 3369A were increased when treated with butylate + R-25788 at 6.9 kg/ha.

Knoxville Test

Differences between R-25788 and R-29148 were dependent upon the herbicide-antidote combination and the hybrid tested. DeKalb XL55 was injured (Tables 15 through 20, pages 32 through 37) when treated with EPTC + R-25788, or vernolate + R-29148. When the corn grain yields (Table 21, page 38) were calculated four hybrids showed yield reductions when treated with vernolate + R-25788, and two hybrids showed yield reductions when treated with vernolate + R-29148. EPTC + R-25788 severely reduced the yield of DeKalb XL55; and R-12001 + R-25788 reduced the grain yield of Pioneer brand 3147.

General Conclusions

R-25788 was found to be superior over R-29148 in formulations with butylate or EPTC. Overall, butylate + R-25788 caused less corn injury than any of the other herbicide-antidote combinations tested. The response to vernolate + R-25788 and vernolate + R-29148 was dependent upon the hybrid tested. There was a trend, though many times not significant; that when the hybrids were treated with vernolate + R-25788 most hybrids had their lowest yields.

LITERATURE CITED

LITERATURE CITED

1. Ashton, F.M. and A.S. Crafts. 1973. Mode of action of herbicides. John Wiley and Sons, Inc. New York. 504 pp.

2. Beard, J.B. 1973. Turfgrass: science and culture. Prentice-Hall, Inc., Englewood Cliffs, N. J. 658 pp.

3. Bliss, C.I. 1967. Statistics in biology. McGraw-Hill Book Co., New York, N. Y. 558 pp.

4. Breck, B.J. 1978. Weeds in agronomic crops-corn preliminary evaluation of herbicides. Research Report Southern Weed Sci. Soc. 31:29.

5. Burnside, O.C., G.A. Wicks, and C.R. Fenster. 1971. Protecting corn from herbicide injury by seed treatment. Weed Sci. 19:565-568.

6. Burt, G.W. 1975. Why does EPTC plus R-25788 injure corn? Northeastern Weed Sci. Soc. Proc. 29:140.

7. Burt, G.W. 1976. Factors affecting thiocarbamate injury to corn II. Weed Sci. 24:327-330.

8. Burt, G.W. and A.O. Akinsorotan. 1976. Factors affecting thiocarbamate injury to corn I. temperature and soil moisture. Weed Sci. 24:319-321.

9. Carringer, R.D. and C.E. Rieck. 1975. Effects of R-25788 on the metabolism of EPTC in corn inbreds. North Central Weed Control Conf. Proc. 30:29.

10. Carringer, R.D., C.E. Rieck, and L.P. Bush. 1978. Metabolism of EPTC in corn. Weed Sci. 26:157-160.

11. Carringer, R.D., C.E. Rieck, and L.P.Bush. 1978. Effect of R-25788 on EPTC metabolism in corn. Weed Sci. 26:167-170.

12. Carringer, R.D., C.E. Rieck, and C.G. Poneleit. 1974. Corn inbred responses to EPTC, butylate, vernolate and two protectants. Proc. North Central Weed Control Conf. 29:32.

13. Casida, J.E., R.A. Gray, and H. Tilles. 1974. Thiocarbamate sulfoxide: potent, selective and biodegradable herbicides. Sci. 184:573-574.

14. Chang, F.Y., F.D. Bandeen, and G.R. Stephenson. 1972. A selective antidote for prevention of EPTC injury in corn. Canadian Journal of Plant Sci. 52:707-714.

15. Chang, F.Y., F.D. Bandeen, and G.R. Stephenson. 1973. Comparative effects of three EPTC antidotes. Weed Sci. 21:292-295.

16. Chang, F.Y., F.D. Bandeen, and G.R. Stephenson. 1973. N,N-Diallyl1-dichloroacetamide as an antidote for EPTC and other herbicides in corn. Weed Research 13:399-406.

17. Crook, J.J. 1975. A status report of thiocarbamate injury to corn on the Maryland Eastern Shore. Northeastern Weed Sci. Soc. Proc. 29:49-54.

18. Dawson, J.H. 1963. Development of barnyardgrass seedlings and their response to EPTC. Weeds. 11:60-66.

19. Dawson, J.H. 1963. Effects of EPTC on barnyardgrass seeds. Weeds. 11:184-186.

20. Donald, W.W. and R.S. Fawcett. 1975. Prevention of EPTC injury to hybrid corn with antidote R-29148 and exogenous GA_3. North Central Weed Control Conf. Proc. 30:28-29.

21. Donald, W.W. and R.G. Harvey. 1976. The role of gibberellins in the abnormal morphogenesis of EPTC injured corn seedlings. North Central Weed Control Conf. Proc. 31:28.

22. Graves, C.R. 1976. 1976 performance of field crop varieties. Tennessee Expt. Sta. Bul. 565. 75 pp.

23. Graves, C.R. 1977. 1977 performance of field crop varieties. Tennessee Agric. Expt. Sta. Bul. 572. 79 pp.

24. Hahn, R.R. and M.G. Merkle. 1973. Altering sorghum tolerance to alachlor. Proc. So. Weed Control Conf. 26:173.

25. Hahn, R.R. and M.G. Merkle. 1972. Effects of seed treatments on grain sorghum tolerance to alachlor. Proc. So. Weed Sci. Soc. 25:166.

26. Hickey, J.S. 1973. Effect of alachlor and 1,8-naphthalic anhydride on the growth and development of grain sorghum and corn seedlings. Ph.D. Dissertation. Univ. Tennessee, Knoxville, Tennessee.

27. Hickey, J.S. and W.A. Krueger. 1974. Alachlor and 1,8-naphthalic anhydride effects on sorghum seedling development. Weed Sci. 22:86-90.

28. Hickey, J.S. and W.A. Krueger. 1974. Alachlor and 1,8-naphthalic anhydride effects on corn coleoptiles. Weed Sci. 22:250-252.

29. Jeffery, L.S., J. Connell, and T.H. Morgan. 1971. Performance of 1,8-naphthalic anhydride as a chemical antidote to decrease injury to corn from butylate and EPTC. Proc. So. Weed Sci. Soc. 24:156.

30. Jennings, V.M. and R.F. Nyvall. 1977. Misapplied row crop herbicides: symptoms and problems. Iowa State Univ. Cooperative Ext. Serv. Pm-738. p. 9.

31. Kapusta, G. 1970. Naphthalic anhydride antidote for EPTC on corn. North Central Weed Control Conf. Research Report. 27:79.

32. Kearney, P.C. and D.D. Kaufman. 1975. Herbicides: chemistry, degradation and mode of action. Marcel Dekker, Inc. New York, N. Y. 1:324-346.

33. Kenega, C.B. 1974. Principles of phytopathology. Balt Publishers, Lafayette, Indiana. 402 pp.

34. Lay, M.M., J.P. Hubbell, and J.E. Casida. 1975. Dichloroacetamide antidotes for thiocarbamate herbicides: mode of action. Sci. 189:287-288.

35. Nalewaja, J.D., R. Behrens, and A.R. Schmid. 1964. Uptake, translocation and fate of EPTC-C^{14} in alfalfa. Weeds 12:269-272.

36. Pfund, J.H. and C.W. Crum. 1977. Inheritance of tolerance to Eradicane in maize. 1977 Agronomy Soc. of Amer. Proc. 69:66.

37. Rains, L.J. and O.H. Fletchall. 1969. The use of chemicals to protect crops from herbicide injury. North Central Weed Control Conf. Proc. 26:42.

38. Rincon, D.J. and G.F. Warren. 1978. Effect of five thiocarbamate herbicides on purple nutsedge. Weed Sci. 26:127-131.

39. Thomas, V.M. and R.A. Gray. 1974. Behavior and persistence of N,N-diallyl-2,2-dichloroacetamide (R-25788) in soils. Abstracts 1974 meeting of the Weed Sci. Soc. of Amer. 2, 3.

40. Ware, G.W. 1975. Pesticides an auto-tutorial approach. W.H. Freeman and Co., San Francisco, Calif. 191 pp.

41. Weed Science Society of America. 1974. Herbicide Handbook, 3rd ed. Champaign, Illinois. 430 pp.

42. Wicks, G.A. 1970. Protection of corn by EPTC and butylate by seed treatment. North Central Weed Control Conf. Research Report. 27:97.

43. Wilkinson, R.E. and A.E. Smith. 1975. Thiocarbamate inhibition of fatty acid biosynthesis in isolated spinach chloroplasts. Weed Sci. 23:100-104.

44. Wright, T.H. and C.E. Rieck. 1973. Differential butylate injury to corn hybrids. Weed Sci. 21:83-85.

45. Wright, T.H. and C.E. Rieck. 1974. Factors affecting butylate injury to corn. Weed Sci. 22:83-85.

46. Wyse, D.L., W.F. Meggitt, and D. Penner. 1976. Factors affecting EPTC injury to navy bean. Weed Sci. 24:1-4.

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