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THE INFLUENCE OF ENVIRONMENTAL
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TOLERANCE TO TRIFLURALIN

presented by

FRANK CLARENCE ROGGENBUCK

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of the requirements for

MASTER'S degree in CROP AND SOIL SCIENCE

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THE INFLUENCE OF ENVIRONMENTAL
AND GENETIC FACTORS ON CORN (Zea mays L.)
TOLERANCE TO TRIFLURALIN

By

Frank Clarence Roggenbuck

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ABSTRACT

THE INFLUENCE OF ENVIRONMENTAL AND GENETIC FACTORS ON CORN (Zea mays L.) TOLERANCE TO TRIFLURALIN

By

Frank Clarence Roggenbuck

Corn (Zea mays L.) can be injured by carry-over of trifluralin (a,a,a,-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine) from one crop year to the next. Controlled environment, greenhouse, and field experiments were conducted to determine factors that could influence corn tolerance to trifluralin residues. One hundred eight (108) inbred lines and 5 hybrids were tested to determine genetic variability of corn tolerance to trifluralin. Several corn hybrids were found to be more sensitive to trifluralin at 15 C than at 25 C. Soil moisture had lesser but significant effects for certain hybrids. The addition of phosphorus and alachlor [2-chloro-2',6'-diethyl-N-(methoxymethyl)acetanilide] did not alter corn tolerance to trifluralin. Shallow trifluralin incorporation reduced stand, whereas deep incorporation reduced shoot height and increased stunting. A wide range of trifluralin tolerance was evident in the corn tested. The results suggest two mechanisms for trifluralin tolerance in corn.

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To my wife Laurie, for her patience,
understanding, and help in completing
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INTRODUCTION

Although conservation tillage may be a novelty in certain regions of the United States, the practice appears to be increasing in corn and soybean growing areas. Conservation tillage practices leave persistent pesticides near the soil surface, particularly if the pesticides are not subject to leaching.

In northern areas and in other areas that experience cool, dry years, trifluralin has been reported to persist in high enough concentration to injure subsequent crops. When conservation tillage methods are used to plant corn following a trifluralin-treated soybean crop, there also appears to be an even greater chance for corn injury.

The objectives of this study were to determine (1) the conditions under which trifluralin injury to corn was most likely to occur, and (2) the variability in the genetic tolerance of corn to trifluralin.

CHAPTER 1

EFFECT OF TRIFLURALIN ON CORN

INTRODUCTION

In 1960, researchers from Eli Lilly and Company reported on the herbicidal properties of several substituted 2,6-dinitroanilines (5). Trifluralin¹ was the first herbicide of this class developed for agronomic crops (84). It was most effective as a soil-incorporated, preemergence herbicide in broadleaf crops. Trifluralin selectively killed grass weeds and some broadleaf weeds with limited to no crop injury to soybean (Glycine max (L.) Merr.), peanut (Arachis hypogaea L.), and cotton (Gossypium hirsutum L.). It was first registered for use on cotton in 1963 (77).

The agronomic potential of the dinitroanilines was quickly identified and other companies developed herbicides in this class of compounds. Their greatest use has been in soybean and cotton, with other registered uses in agronomic, vegetable, and tree fruit crops (10).

There have been several reviews published on the dinitroanilines (10, 44, 76, 90, 112). The scope of this review will be limited to one dinitroaniline, trifluralin, its herbicidal effects on corn, and factors that influence corn tolerance.

¹ a,a,a-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine (TREFLAN)

HERBICIDAL EFFECTS OF TRIFLURALIN ON CORN

Corn often follows soybean in a cropping rotation. In 1980, trifluralin was used on approximately 30 million acres, or one-third, of the soybeans in the major soybean producing states (115). There have been numerous casual observations that following cool, dry years there is sufficient trifluralin residue present in the second crop year to cause injury to corn. Trifluralin carry-over injury to corn has been reported in the literature (29). The factors involved in the injury of corn by carry-over amounts of trifluralin have not been fully determined. With few exceptions, trifluralin is more toxic to monocots than dicots (12).

Corn is a monocot that is injured or killed when grown in soil treated with trifluralin (38, 55, 56, 100); however, corn seed germination was not inhibited when treated with trifluralin in the laboratory (100). Trifluralin is absorbed by both emerging shoots and roots of plants from treated soil (78). Prendeville et al. (88) found corn shoots to be the major site of trifluralin uptake. When corn seedlings are treated so that only the shoot or only the root is exposed to trifluralin, the greater sensitivity of the shoot becomes apparent (71). The herbicidal effect must take place between the time of radicle and shoot emergence from the seed and subsequent emergence of the seedling from the soil (76).

Trifluralin injury in corn is characterized by a swelling of the root tip (16, 38, 55, 100, 102). Corn root elongation is inhibited by trifluralin and the root tip swells within 6 hours after treatment (56). Lateral roots are inhibited by trifluralin (38, 55, 56, 102).

Hacskeylo and Amato (38) found "root pruning" in cotton, but a total failure of radicle and seminal roots in corn from the same concentration of trifluralin. Corn shoots emerging from the trifluralin treated soil are prostrate and twisted, stunted, and exhibit an increased purple coloration, similar to phosphorous deficiency (38, 76).

Bayer et al. (17) summarized anatomical and morphological effects of trifluralin in cotton roots. Time course studies of root tip cell development in the presence of herbicidal levels of trifluralin demonstrated that elongation ceased within 24 hours of treatment. Enhanced radial expansion compensated for inhibited elongation, resulting in approximately the same volume change for treated and untreated tissues. This radial expansion produced the commonly observed bulbous root tips. As the time of exposure increased, the proportion of apical meristem cells to differentiated cells decreased. Meristematic cells ultimately vacuolated with a general loss of organization in the tissue.

Cytological studies with corn roots treated with trifluralin indicate that mitosis is inhibited, resulting in multinucleate cells (16, 38). Bartels and Hilton (16) observed that trifluralin arrested cell division at metaphase in corn root tips. The absence of cell plate and cell wall formation was noted in trifluralin treated roots of corn (38). Trifluralin caused the loss of both cortical and spindle microtubules from corn root cells (16). Hess and Bayer (45, 46) concluded that at obtainable water-soluble concentrations, trifluralin specifically inhibits microtubule-mediated processes in plants.

MORPHOLOGICAL AND PHYSIOLOGICAL COMPONENTS OF SELECTIVITY

The factors that contribute to the selectivity of trifluralin between dicots and monocots are not clear. There would appear to be two components to selectivity; a morphological and a physiological component.

The morphological component involves the root systems of dicots and monocots. In dicots, the primary root tends to grow vertically downward forming a tap root system (7). Lateral roots occur initially as branches of the primary root. The primary root system remains throughout the life of the plant. This system would be typical for soybeans.

In many monocots, particularly in the grasses, the primary root system stops growing, and may even die, while the plants are young (7). This system is replaced by a fibrous root system that has numerous adventitious roots originating close to the base of the stem. The adventitious roots tend to grow laterally at first, and then turn downward in the soil. The roots of corn plants first grow nearly parallel to the soil surface, remaining in the upper 7.5 to 15 cm of soil. When the plants have their seventh or eighth leaf, and the roots have extended 0.6 to 1 m from the base of the stalk, the roots turn downward rather abruptly (7).

In the dicot cotton, when the tap root grows through the layer of soil treated with trifluralin, lateral root production in that zone is restricted (8, 17). Trifluralin is strongly bound to the soil, does not leach downward, and is active throughout the depth to which it is incorporated (9). The inhibition of lateral roots by

trifluralin was affected more by depth of incorporation than by dosage (8, 73, 107). Lateral or secondary roots below the treated zone may be nearly normal and shoots are usually uninjured. The growth of the tap root is unaffected by trifluralin at doses which completely inhibit lateral root formation (8, 17, 57). It has been hypothesized that cells of the pericycle and endodermis are more sensitive to trifluralin than cells in the tap root tip (17, 57).

The early lateral growth of corn roots maximizes their contact with trifluralin treated soil. Corn roots tend to stay in the top layer of soil, prolonging injury, while dicot roots tend to grow rapidly downward and escape injury. During the seedling stage, root growth is critical in the establishment of one species and failure of another (113). The most rapidly established species will have a competitive advantage and will seriously delay growth of other species.

The physiological component of selectivity is more complex than the morphological component. The differences between dicots and monocots are not as obvious. The physiological component can be divided into three categories: 1. absorption and translocation; 2. lipid content; and 3. metabolism.

The amount of trifluralin absorbed and translocated by plant tissue, by whatever mode of presentation or site of contact, is relatively small (112). Evidence for and against absorption and translocation is present in the literature. Parka and Soper (76) summarized the topic by stating that trifluralin is either absorbed or adsorbed by the roots because of their proximity to the herbicide, while translocation from the root to the shoot is minimal. Corn

shoots are more sensitive to trifluralin than the roots (71). Once the corn shoot has emerged from the soil, little translocation of trifluralin from the roots is evident. However, absorption by the shoot of trifluralin which volatilized from the treated soil can cause shoot injury (71, 111).

The critical processes controlling selectivity may occur within the cell walls and the cytoplasm. Strang and Rogers (110) used microradioautography to study the absorption and translocation of ^{14}C -trifluralin by cotton and soybean. Radioactivity was found primarily on the surface of the roots due to a tenacious adsorption or binding to the epidermis or cuticle. The epidermis was the major barrier to entrance of trifluralin. Movement through the cortex appeared to be primarily via the cell walls, with binding occurring in the cortical cell walls. Little movement out of the soybean root was observed, but some radioactivity was found in cotton leaves. Entrance of radioactivity into the roots of these species was greatly facilitated by breaks in the epidermis, as might occur from seedling diseases, mechanical damage, or lateral root emergence.

Lateral roots develop from a cell layer deep in the root called the pericycle. As lateral roots form, they break through the endodermis, creating an opening in the suberized layer called the Casparian strip. In corn, cortical cells in the path of the emerging root primordia collapse completely as they are contacted, allowing its unimpeded passage (7). As Strang and Rogers (110) suggest, a pathway for absorption of trifluralin to the interior of the root is opened as lateral roots form. This pathway may help explain the increased sensitivity of lateral roots compared to tap roots. When

the primary barrier of the root, the epidermis, is crossed, binding to cell walls occurs as trifluralin moves into the root. A gradient develops from the relatively high concentration outside the root to very low concentrations at the dividing root tip cells that are most sensitive to trifluralin. Sawamura and Jackson (98) worked with cell cultures of Tradescantia paludosa and found disrupted phases of mitosis at 0.2 ppb trifluralin. The pathway consists of crossing the epidermis, movement via cell walls to the plasmalemma, crossing the plasmalemma to enter the cytoplasm, and reaching the sensitive microtubules. The ability of this pathway to bind or detoxify trifluralin may be a key step in selectivity.

Lipid content is the second physiological component of selectivity. Lipids may play a role in reducing the amount of trifluralin that reaches the interior of the root. Trifluralin is highly lipid soluble and has been shown to influence several processes that involve lipids structurally or functionally. Mann and Pu (58) found no effect of trifluralin on lipogenesis as evidenced by incorporation of malonic-2-¹⁴C acid into lipids in hemp sesbania (Sesbania exaltata (Raf.) Cory). Penner and Meggitt (81) observed that treatment with trifluralin did not alter the percent oil content of soybean seeds. However, at 1.12 kg/ha, trifluralin significantly reduced the stearic acid and increased the linoleic acid content of seeds compared to the controls. The same researchers reported that chemical weed control practices did not alter percent oil or oil quality in corn grain (82). In contrast, Ashton et al. (11) reported that lipid synthesis was the most sensitive metabolic site of inhibition by trifluralin in red kidney bean (Phaseolus vulgaris L.)

single cells. Trifluralin inhibited lipid synthesis by 27% at 10^{-5} M.

Crop seeds differ extensively in lipid and fatty acid composition (27, 48, 53, 119). The lipid content of nearly all trifluralin-tolerant weed seeds was found to be within the range of commercial oil seeds such as soybeans and corn (47, 99, 109).

Susceptibility of plants to trifluralin decreased as the percentage of total lipid in dry seeds increased (68). There was also a significant negative correlation between root lipid content and sensitivity to trifluralin (68). Corn cultivars with a wide range of seed lipid content (4.45 to 17.0% of dry weight) were grown in trifluralin-treated soil. Seedlings grown from seeds with high lipid levels were observed to accumulate higher percentages of lipids in their roots and were less susceptible to trifluralin than roots with lower lipid levels (67). Externally applied lipids (such as D-a-tocopherol, oleic acid, corn oil, and others) protect plants from trifluralin injury, both in the laboratory and in the field (24, 25, 47).

Much of the lipid found in cells occurs in membranes. The cell membrane consists of a protein-lipid micellar structure that may also trap small amounts of lipid soluble compounds that move into it (118). The plasmalemma may contain higher levels of lipid in lipid-rich roots, allowing it to trap more trifluralin. Hilton and Christiansen (47) hypothesized that selective phytotoxicity of trifluralin to young seedlings was determined in part by the amount of endogenous lipid available to trap trifluralin and keep it from its site of phytotoxic action. Ndon and Harvey (69) state that differential rates of de novo synthesis of membrane lipids in roots

may account for the differences of lipids in roots and, hence, the differential responses of roots to trifluralin. In addition, total oil content of corn has been positively correlated with early spring vigor (37). High lipid content may protect corn from trifluralin as well as increase vigor early in the growing season. Several reviews have been published on plant membrane lipid composition and permeability (18, 104, 114, 117).

Metabolism is the third physiological component contributing to selectivity. Hatzios and Penner (42) reviewed the role of herbicide metabolism in plants and in selectivity. Limited absorption and translocation have restricted the amount of trifluralin within the roots of some species, contributing to selectivity. Lipid content also affects selectivity. When trifluralin enters the symplast of the plant, it is subject to the final protective mechanism the plant has to prevent phytotoxicity, metabolism.

After crossing the plasmalemma, trifluralin is subject to metabolism or alteration which may limit phytotoxicity. If it is bound in the lipid portion of the plasmalemma, it can also be subject to metabolism. Morre (64) reviewed membrane turnover and two models of membrane degradation. Various times are reported for membrane turnover, ranging from several hours to several days. In one model, membrane constituents associate and dissociate from the membranes, and only in the dissociated state are they subject to intracellular degradative processes. In the other model, organelles or fragments of membranes are internalized by autophagic vacuoles. Lysosomal enzymes are added and membrane breakdown is completed within the confines of the resulting digestive vacuole. The products are then

available for redirected synthesis of lipid membranes. If trifluralin were present in the membrane, it could be altered by lysosomal enzymes as well.

If trifluralin were released as in the first model, or simply crossed the plasmalemma and entered the cytoplasm, metabolism could also occur. Probst et al. (91) grew soybeans and cotton plants in soil containing ^{14}C -trifluralin. The resulting radioactivity in the plants was distributed in lipids, glucosides, hydrolysis products, proteins, and cellular fractions. They concluded that the universal distribution of the radioactivity without definite identification of trifluralin or recognizable metabolites suggests nondescript incorporation or total metabolism of trifluralin.

Carrots (Daucus carota L.) were grown in greenhouse soil into which ^{14}C -trifluralin was incorporated (33). After 110 days, two-thirds of the radioactivity in the root was in the surface layer. In general, the amount of trifluralin progressively decreased from the surface to the center of the root; however, a somewhat higher amount was found in the layer containing the xylem-phloem junction. The major compound found was unaltered trifluralin.

Biswas and Hamilton (19) exposed peanuts and sweet potato (Ipomea batatas Lam.) roots to solutions containing ^{14}C -trifluoromethyl-labeled trifluralin. After 72 hours, less than 1% of the radioactivity was unaltered trifluralin in peanut, whereas this value was 17% in sweet potato. Penner and Early (80) treated corn roots with ^{14}C -trifluralin and examined it after 12 hours. Less than 9% of the ^{14}C co-chromatographed with trifluralin. Sixty percent of the ^{14}C was present in the 80% methanol-insoluble residue. The remaining

radioactivity was in water-soluble and hexane-soluble fractions and was not trifluralin. These results indicated that corn roots rapidly metabolized trifluralin.

A related dinitroaniline, fluchloralin [N-(2-chloroethyl)-2,6-dinitro-N-propyl-4-(trifluoromethyl)aniline] differs from trifluralin only by the substitution of one chlorine for one hydrogen atom. Marquis et al. (59) discovered that fluchloralin was metabolized by soybean roots at a rate sufficient to prevent irreversible injury while corn roots metabolized it more slowly and were severely injured. Fluchloralin selectivity between corn and soybeans appeared due to both the rate of metabolism and the ability of soybean roots to escape the herbicide zone more rapidly than corn.

Currently, trifluralin selectivity in corn can only be achieved by utilizing a post-plant layby application made to the soil and shallowly incorporated with a rolling cultivator (1, 3, 15, 35, 63). The corn needs to be at least 20 cm tall and the brace roots covered with soil by cultivation prior to the layby herbicide treatment. The age of the corn, the shallow incorporation, and the strong soil adsorption likely limited the injury to the corn shoots and roots (51, 87, 97).

FACTORS INFLUENCING TOLERANCE

The limited tolerance of corn to trifluralin takes on new meaning when the current patterns of tillage practices are examined and future projections are considered. A recent survey of research and extension workers in 25 leading corn states indicated that no-till

corn will increase from 5 to 10% of the crop in 1980 to 26% by 1990 (122, 123). Reduced tillage corn will increase from 28% of the crop in 1980 to 48% in 1990. These results are fairly well in agreement with predictions made in a U.S.D.A. technology assessment report on minimum tillage in 1975 (116). Phillips et al. (83) predicted that 65% of the corn and soybeans in the southern corn belt would be grown by no-till methods by the year 2000.

Currently, the most common reduced tillage method involves fall chisel plowing and one-pass spring seedbed preparation (108). Trifluralin was estimated as being applied to approximately a third of the soybean acreage in 1980 in the major soybean producing states (115). Corn planted with conservation tillage, which can be any combination of no-till or reduced tillage practices less than moldboard plowing, is a common crop following soybeans. Burnside (22) maintains that trifluralin persistence is extremely important in the western part of the corn belt due to the widespread use of this herbicide on soybeans and because much of the treated land is rotated to grass crops. When these facts are combined with the finding that conservation tillage can increase the chance of carry-over trifluralin injury on corn (29), a problem of increasing concern is evident.

To be a problem, trifluralin must persist from the application year to subsequent cropping year. The evidence for and against this persistence is extensive (2, 14, 20, 21, 23, 30, 34, 39, 40, 41, 43, 50, 52, 60, 61, 62, 73, 77, 89, 91, 92, 93, 95, 96, 97, 101, 106, 121, 125). Helling (44) concluded that for normal use rates, trifluralin persistence in soils ranges from 5 to 6 months.

Persistence increases with decreasing soil temperature and moisture content; seasonal carry-over sometimes occurs.

Areas likely to have carry-over problems would be northern areas with shorter growing seasons, areas with low amounts of rainfall, or any area that has a cool and/or dry growing season. Conservation tillage would likely increase the problem in these areas as well.

Since trifluralin is strongly adsorbed to soil organic matter (49) and does not leach (9) it stays in the zone of incorporation. Conservation tillage limits the dilution of this layer with deeper soil areas. If carry-over trifluralin is present, corn planted in this layer of treated soil will show injury. Moldboard plowing of soil containing phytotoxic concentrations dilutes the trifluralin concentration and places it below the zone of maximum phytotoxicity (22). Plowing provides a practical means of eliminating phytotoxic amounts of trifluralin when a soil residue problem exists (23, 52).

Conservation tillage leaves more crop residue on the soil surface than conventional moldboard plowing. This residue tends to keep the soil shaded and cooler in the early spring, reducing soil temperatures (122). Corn absorbs more trifluralin at low soil temperatures than at higher soil temperatures (79). Plant growth is slower at lower soil temperatures. The longer that sorghum (Sorghum bicolor (L.) Moench) shoots were exposed to trifluralin, the greater the injury (13).

Conservation tillage is an integral part of double cropping systems. Double cropping involving minimum tillage planting has become popular in parts of this country (70). It reduces the time available for trifluralin degradation, as a second crop is planted

later the same season. The effect of tillage is evident on trifluralin carryover in this type of cropping system. Plowing eliminated injury to sweet corn following trifluralin treated canning peas, while on minimum tillage plots, the sweet corn was stunted, had reduced stands and reduced yield (69). In another study of double cropped grain sorghum, corn, and soybeans following trifluralin treated canning peas, the soybeans had no injury, the corn was slightly injured, and the sorghum was severely injured (70). The sorghum stand was reduced by 44%.

The carry-over and lack of degradation of trifluralin through the cold winter period can be exploited in conservation tillage systems. A system has been described that recommends application of trifluralin directly to crop residue in the fall (75). The herbicide is incorporated with the fall primary conservation tillage operation. Subsequent secondary tillage in the spring incorporates trifluralin adequately for effective weed control during the growing season.

While conservation tillage tends to reduce the tolerance of corn to trifluralin, there is some evidence that genetic tolerance may exist that could be exploited. Davis et al. (26) tested 18 parental lines and 34 single crosses for tolerance to 0.56 kg/ha of trifluralin. The lines ranged from 0 to 70% injury in their response to trifluralin. Genetic resistance to trifluralin has been developed in butternut squash (Cucurbita moschata Poir) by a selective breeding program (4). Genetic control of enzyme systems responsible for herbicide metabolism in corn with herbicides other than trifluralin has been reported (28, 36, 103). Differential responses of inbred as well as hybrid corn have been shown for several other herbicides (6,

31, 32, 66, 72, 85, 94, 124). Development and incorporation of genetic tolerance of corn to trifluralin would solve the problem of carry-over.

CONCLUSIONS

In this discussion, three broad areas of effects of trifluralin on corn have been examined: 1. herbicidal action; 2. the morphological and physiological components of selectivity; and 3. factors that can influence tolerance. This examination of the literature reveals that several important questions concerning the effect of trifluralin on corn are still unanswered.

1. What specific environmental, chemical, and cultural factors interact with trifluralin residue carry-over to cause trifluralin injury in corn?

2. What corn hybrids are particularly sensitive or tolerant to trifluralin carryover residues? Several seed producers have advised buyers of their seed in regard to the sensitivity of a particular hybrid to certain herbicides (105). If this question can be answered, farmers can be advised what varieties to grow or not grow if they suspect a trifluralin carry-over problem.

3. Can one select for morphological and physiological components in corn that influence its response to trifluralin? The literature suggests that it may be possible. Nagel (65) has been able to genetically select for plants with a strong, spreading type root system with an abundance of secondary and fine roots. Any corn line that could rapidly penetrate downward through a trifluralin layer would sustain less injury than one that followed the normal early

shallow rooting pattern. Genetic modifications of oil content and fatty acid composition in corn kernels is feasible (54, 86, 119, 120). Field tolerance of flax (Linum usitatissimum L.) lines to trifluralin was thought to be a function of more than one mechanism (74). Advances made in any area could lead to a more tolerant corn line.

4. What is the sensitivity of corn inbred lines to trifluralin carry-over residues? When identified, very sensitive inbred lines could be avoided for use in producing hybrids. Tolerant inbred lines could be used to produce crosses with hybrid tolerance.

Answers to these questions could help in eliminating the current problem of corn injury from trifluralin carry-over, a problem that will likely increase in magnitude as conservation tillage increases in the future. If genetic bases for tolerance in corn can be defined, advances in breeding are possible.

If corn tolerance could be advanced to a level at which trifluralin could be used as a weed control agent without crop injury, it would be a comparatively cheap herbicide to use in corn. The combination of trifluralin to control grasses and a low rate of a triazine herbicide to control broadleaf weeds could provide economical weed control in corn. These answers should be valuable to industry, farmers, and consumers.

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CHAPTER 2

FACTORS INFLUENCING CORN TOLERANCE TO TRIFLURALIN

Abstract. Corn (Zea mays L.) can be injured by carry-over of trifluralin (a,a,a-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine) from one crop year to the next. Factors that influence corn tolerance to carry-over concentrations of trifluralin were studied in controlled environment chambers and greenhouse experiments. For several hybrids, greater injury occurred at low than high temperatures. This injury was especially evident for Pioneer 3320 and Pioneer 3572 if the soil moisture was at 100% field capacity. Addition of phosphorus fertilizer did not interact with trifluralin to increase injury, but did interact with alachlor [2-chloro-2',6'-diethyl-N-(methoxymethyl)acetanilide]. Alachlor plus trifluralin injured corn in an apparently additive manner. Significant differences were found in genetic tolerance of corn to trifluralin within a group of hybrids. Tolerance of specific hybrids to trifluralin was altered by environmental conditions.

INTRODUCTION

Effective herbicides should provide weed control for a cropping season, then degrade to innocuous products (24). Persistence beyond the period necessary for control leads to carry-over problems in succeeding crops. Trifluralin is used extensively for season-long

weed control in soybeans (Glycine max L. (Merr.)). Corn often follows soybeans in a cropping rotation and can be severely injured by trifluralin carry-over.

Fink (16) reported injury to corn following soybeans treated with trifluralin in West Central Illinois. This injury was thought to be due to a relatively dry soybean season combined with a lack of moldboard plowing. Moldboard plowing dilutes the trifluralin concentration and places it below the zone of maximum phytotoxicity (9, 10, 16, 24). This practice provides a practical means of eliminating trifluralin carry-over problems.

The persistence of trifluralin reflects the total of all processes (physical, chemical, and biological) modifying the herbicide in the soil (10). The eventual fate of trifluralin presumably is decomposition, but the variable rates of breakdown reactions lead to the occurrence of some soil residues (10). Helling (21) reviewed and summarized the soil persistence of dinitroaniline herbicides. He concluded that trifluralin persistence for normal use rates was 5 to 6 months and increased with decreasing soil temperature and moisture content. Seasonal carry-over occurred with cool, dry conditions.

Temperature, soil moisture, soil phosphorous levels, other herbicides, and genetic differences may all influence the tolerance of corn to trifluralin, but these factors have not been thoroughly researched. Hammerton (19) reviewed the effects of temperature before, during, and after herbicide application. He proposed that plants grown at different temperatures may vary both morphologically and metabolically. An increase in phytotoxicity at 10 C has been

reported for atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine] on corn (46). This increase was attributed to reduced detoxication as well as greater foliar penetration under wet conditions. Penner (36) reported that trifluralin-treated corn showed a greater reduction in dry weight at 30 C than at 20 C in comparison to the control. However, corn accumulated a higher concentration of ^{14}C -trifluralin in both roots and shoots when grown at 20 C compared to 30 C (36). Temperatures between 20 and 30 C did not effect the phytotoxicity of trifluralin to soybeans or navy beans (Phaseolus vulgaris L.) (36, 37). Temperatures within the range of 10 to 24 C did not effect trifluralin toxicity to barley (Hordeum vulgare L. 'Larker') (30). An increase in phytotoxicity with an increase in temperature have been reported for several herbicides (11, 25, 29, 31, 36, 37, 38, 42, 48, 50).

Soil water content may influence herbicide phytotoxicity (26, 27, 44, 49). Herbicide phytotoxicity generally increases as soil water content increases. However, Stickler et al. (44) found a decreasing response of giant foxtail (Setaria faberii Herrm.) to trifluralin with increasing moisture. Mass flow and diffusion were probably the major factors involved in providing dinitroaniline herbicide activity in the soil (23). Bode et al. (6) found trifluralin diffusion to be low in air-dry soil at all temperatures studied. Diffusion increased to a maximum between 8 and 15% w/w soil moisture content and then decreased steadily as moisture content increased. Standifer and Thomas (43), however, have noted that trifluralin is generally effective under dry soil conditions. There was not a marked difference in trifluralin phytotoxicity to oats (Avena sativa L.

'Dal') between 55 and 100% soil field moisture capacity (23).

Monocot plants emerge from trifluralin-treated soil with an increased red-purple coloration, similar to phosphorus deficiency (35). Inhibition of root growth is also a characteristic of phosphorus deficiency and trifluralin injury. Cathey and Sabbe (12) reported the phosphorus uptake by soybean and cotton (Gossypium hirsutum L.) was decreased when the phosphorus and trifluralin were located in the same soil zone. Trifluralin has also been shown to inhibit phosphorus uptake by tomato (Lycopersicon esculentum Mill.) (52), soybean, and oat (8). Trifluralin caused a greater reduction of tomato root growth at low phosphorus rates than at high rates (52). Phosphorus was less effective in promoting root growth as the trifluralin rate increased.

The phosphorus level in the soil may also influence herbicide phytotoxicity (1, 14, 41, 45, 47). Rahman et al. (39) discovered that the addition of low rates of phosphorus (up to 300 ppmw) had either no effect or slightly enhanced the phytotoxicity of trifluralin to German millet (Setaria italica (L.) Beauv.). At high rates, phosphorus significantly reduced the toxicity of the herbicide.

Combinations of herbicides applied together can result in synergistic, antagonistic, or additive effects (20). An interaction is possible between trifluralin residues and the herbicide applied for weed control in corn. The effect of the combination of linuron [3-(3,4-dichlorophenyl)-1-methoxy-1-methyl urea] and trifluralin on three grass species was found to be additive (28). Diuron [3-(3,4-dichlorophenyl)-1,1-dimethylurea] or dichlobenil

(2,6-dichlorobenzonitrile) were combined with trifluralin to treat black mustard (Brassica nigra L. 'Alsace') or sorghum (Sorghum vulgare Pers. 'Hybrid 610') (22). The effect was found to be additive for both species with both herbicide combinations. Data on alachlor, a commonly used corn herbicide, and trifluralin combinations were not available in the literature.

It was suggested in 1960 that greater emphasis be given to the role of genetics in the use of agricultural chemicals to attain the goal of protecting the economic crop from both chemical and pest damage (51). Variations in tolerance of corn hybrids and inbred lines have been reported for atrazine, simazine [2-chloro-4,6-bis (ethylamino)-s-triazine], diclofop [2-[4-(2,4-dichlorophenoxy) phenoxy] propanoic acid], butylate (S-ethyl diisobutylthiocarbamate), EPTC (S-ethyl dipropylthiocarbamate), alachlor, and propachlor (2-chloro-N-isopropylacetanilide) (2, 3, 4, 5, 17, 18, 32, 33, 40). Davis et al. (13) tested 18 inbred lines and 34 single crosses of corn for tolerance to 0.56 kg/ha of trifluralin and found a range from 0 to 70% injury. Francis and Hamill (17) conducted a greenhouse study of corn seedling tolerance to alachlor and concluded that reliable prediction of hybrid tolerance from knowledge of inbred response is not possible.

The objective of this study was to determine the conditions in which trifluralin injury to corn was most likely to occur by evaluating the influence of trifluralin levels, temperature, soil moisture, soil phosphorus levels, an alachlor application, and a range of hybrids on trifluralin injury to corn.

MATERIALS AND METHODS

Influence of environment. Controlled environment chambers were used to test the effect of temperature, soil moisture, and trifluralin levels on four corn hybrids, Pioneer 3747¹, Pioneer 3320, Pioneer 3572, and Pioneer 3541. The chambers were kept at a constant temperature of either 15 ± 2 or 25 ± 2 C, with a 14 hr daylength at an irradiation of $400 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. A Marlette sandy clay loam (Glossoboric Hapludalf fine-loamy, mixed, mesic) was mixed (1:1,v/v) with sand to formulate a soil mix with 2.0% organic matter, a pH of 7.7, and a phosphorus content of 43 kg/ha. This soil mix was used for all experiments in the study. The field moisture capacity (FC) was determined according to Fedorovskii (15). The two soil water contents used in the experiments were 11.6% w/w (48% soil FC) and 24.2% w/w (100% soil FC). Treatments of 0, 0.22, or 0.45 kg/ha trifluralin were applied in water at 281 L/ha to air-dry soil mix in 946 ml plastic pots. The treated soil in each individual pot was immediately mixed in a plastic bag to insure uniform incorporation and returned to the pot.

Two corn seeds were planted 2.5 cm deep in each pot and the pots then adjusted to 48% or 100% soil FC. The pots were checked daily and watered to maintain the appropriate soil moisture level. Of the four hybrids tested for tolerance, personnel from Eli Lilly and Company identified Pioneer 3747 and Pioneer 3320 as being susceptible and Pioneer 3572 and Pioneer 3541 as being tolerant to trifluralin

¹ As used throughout this chapter, this format indicates brand-variety, e.g., Pioneer brand, variety 3747.

residues in the field. The plants were harvested 21 days after planting. Shoot and root fresh and dry weight and shoot length data were recorded at harvest. The experimental design was a completely randomized four factor factorial. There were two replications of each treatment with two plants per replication. The entire experiment was repeated and the data presented in the tables are the means of the two experiments.

Influence of phosphorus and alachlor. The influence of phosphorus and alachlor on corn tolerance to trifluralin was tested in a greenhouse study. The phosphorus was obtained as a 0-40-0 analysis granular commercial fertilizer and ground to a fine powder using a mortar and pestle. Phosphorus application rates were 0 or 112 kg/ha, incorporated as described earlier for trifluralin. Trifluralin was applied at 0 or 0.22 kg/ha in water at 281 L/ha and incorporated as previously described. The alachlor was applied preemergence at 0 or 3.36 kg/ha in water at 281 L/ha. Two hybrids were used, Pioneer 3747 and Pioneer 3572. The corn seeds were planted as previously described. Temperatures were maintained at 15 ± 3 C at night and 15 to 21 C during the day. Natural illumination was supplemented by cool-white fluorescent lighting to maintain a daylength of 14 hr. The pots were watered daily as needed. Visual injury ratings were taken 20 and 33 days after planting. The plants were harvested 35 days after planting. Shoot and root length, fresh weight, and dry weight data were recorded at harvest. The experimental design was a completely randomized four factor factorial. The data presented are the means of two experiments with four replications each with two plants per replication.

Genetic variability. A range of corn hybrids were tested for tolerance to trifluralin in a greenhouse experiment. Twelve Pioneer hybrids and one Migro hybrid were treated with 0 or 0.45 kg/ha trifluralin and 0 or 112 kg/ha phosphorus applied and incorporated as described previously. A list of the hybrids included in this experiment is given in the tables. The temperatures, lighting, soil, planting, and watering were as described for the chemical factor experiment. The plants were harvested 35 days after planting. Shoot and root length, fresh weight, and dry weight data were recorded at harvest. The experimental design was a completely randomized three factor factorial. The data presented are the means of two experiments with three replications each with two plants per replication.

Data for all experiments were subjected to analysis of variance and the means separated by the Duncan's multiple range test.

RESULTS

Influence of environment. Among the parameters measured, shoot length and root fresh weight were the most sensitive and precise measures of trifluralin injury. The data for these two parameters are presented as the percent of untreated control for clearer interpretation (Table 1). The means of the data and the percent of control values for the remaining three parameters can be found in the appendix (Tables A1 and A2).

Increasing rates of trifluralin caused a significant reduction in shoot length and root fresh weight averaged over all hybrids (Tables

Table 1. The interaction of trifluralin, soil moisture level, and temperature on two parameters of four Pioneer corn hybrids as a percent of control.^a

Effects to be compared	Trifluralin (kg/ha)	Pioneer hybrid	Soil moisture (% field capacity)	Temperature (C)	Shoot	Root
					length	fresh wt
Interaction	0.22	3747	48	15	89.2 a-e	66.4 abc
				25	90.2 a-e	77.0 ab
			100	15	100.5 ab	65.7 abc
				25	96.6 abc	63.7 bc
		3320	48	15	66.4 hij	46.3 e-h
				25	92.3 a-d	71.1 abc
			100	15	103.6 a	58.5 abc
				25	95.9 abc	78.8 a
	0.45	3572	48	15	74.5 d-j	38.9 f-j
				25	92.5 a-d	47.1 e-h
			100	15	92.1 a-d	62.9 bcd
				25	80.3 c-i	65.8 abc
		3541	48	15	98.7 abc	58.3 cde
				25	87.7 a-f	64.8 abc
			100	15	68.9 f-j	49.6 def
				25	90.5 a-e	72.7 abc
	0.45	3747	48	15	85.6 a-g	48.9 efg
				25	87.5 a-f	38.2 f-j
			100	15	71.8 e-j	44.5 e-h
				25	87.4 a-f	42.2 f-i
		3320	48	15	67.6 g-j	33.5 hij
				25	83.9 b-h	35.6 f-j
			100	15	66.5 hij	32.8 hij
				25	87.6 a-f	45.4 e-h
	3572	48	15	57.1 j	34.6 g-j	
			25	64.7 ij	29.6 ij	
		100	15	62.5 ij	26.4 j	
			25	74.4 d-j	33.3 hij	

Table 1. (Continued)

Effects to be compared	Trifluralin (kg/ha)	Pioneer hybrid	Soil moisture (% field capacity)	Temperature (C)	Shoot length —(% of control)—	Root fresh wt
Interaction	0.45	3541	48	15 25 15 25	86.7 a-f 84.1 b-h 69.6 f-j 90.5 a-e	44.5 e-h 40.8 f-j 34.8 f-j 45.9 e-h
Interaction of hybrid by soil moisture		3747	48		88.1 ab	57.6 a
		100	100		89.1 a	54.0 ab
		3320	48		77.5 c	46.6 c
		100	100		88.4 a	53.9 ab
		3572	48		72.2 c	37.5 d
		100	100		77.3 c	47.1 c
		3541	48		89.3 a	52.1 ab
		100	100		79.9 bc	50.8 bc
Interaction of hybrid by temperature		3747		15	86.8 ab	56.3 a
		3320		25	90.4 a	55.2 a
				15	76.0 cd	42.8 b
		3572		25	89.9 a	57.7 a
				15	71.6 d	40.7 b
		3541		25	77.9 cd	44.0 b
				15	80.9 bc	46.8 b
				25	88.2 ab	56.0 a
Main effect of trifluralin	0.22 0.45				88.7 a 76.7 b	61.7 a 38.2 b

Table 1. (Continued)

Effects to be compared	Trifluralin (kg/ha)	Pioneer hybrid	Soil moisture (% field capacity)	Temperature (C)	Shoot length ——(% of control)——	Root fresh wt
Main effect of hybrid		3747			88.6 a	55.8 a
		3320			83.0 a	50.3 b
		3572			74.7 b	42.3 c
		3541			84.6 a	51.4 ab
Main effect of soil moisture			48		81.8 a	48.5 a
			100		83.7 a	51.4 a
Main effect of temperature				15	78.8 b	46.7 b
				25	86.6 a	53.2 a

a Means within a column within an effects group with a common letter are not significantly different at the 5% level by the Duncan's multiple range test.

1 and 2). However, for individual hybrids this response was not equal under all environmental conditions (Table 1). Pioneer 3572 was the most sensitive to trifluralin injury.

Plant response to the two levels of soil moisture was not significantly different when averaged over all other factors in the study on a percent of control basis (Table 1). However, individual hybrids did show significantly differing responses to the two soil moisture levels (Table 1). Shoot length of Pioneer 3320 was significantly less, shoot length of Pioneer 3747 and Pioneer 3572 the same, and shoot length of Pioneer 3541 greater at 48% soil FC than at 100% soil FC. Root fresh weight of Pioneer 3320 and Pioneer 3572 were significantly less, while Pioneer 3747 and Pioneer 3541 were the same at 48% soil FC compared to 100% soil FC. Significant interaction of hybrids with temperatures was also evident.

Plant response to the two temperatures was significantly different when averaged over all other factors in the study both on a percent of control basis (Table 1) and on a weight or length basis (Table 2). The 15 C treatment caused a greater reduction in the parameters measured than the 25 C treatment overall, although individual hybrids showed differing responses (Table 1). Pioneer 3320 was much more sensitive to trifluralin at 15 C than 25 C. Individual hybrid responses show significant interactions between trifluralin tolerance and soil moisture and temperature levels (Table 1). Thus Pioneer 3541 was also more sensitive to trifluralin at 15 C than 25 C, but only when the soil moisture was at 100% FC.

Influence of phosphorus and alachlor. Visual corn injury from the 0.22 kg/ha trifluralin treatment was insignificant 20 days after

Table 2. The main effects of trifluralin, soil moisture level, and temperature on four Pioneer corn hybrids.^a

Effects to be compared	Trifluralin (kg/ha)	Pioneer hybrid	Soil moisture	Temperature (C)	Shoot		Root	
					length (cm)	fresh wt (g)	dry wt (g)	fresh wt (g)
Main effect of trifluralin	0				19.4 a	1.23 a	0.19 a	2.69 a
	0.22				17.4 b	0.94 b	0.15 ab	1.71 b
	0.45				15.3 c	0.74 c	0.12 b	1.02 c
Main effect of variety		3747			27.0 a	1.62 a	0.25 a	2.71 b
		3320			25.5 b	1.42 b	0.24 a	3.03 a
		3572			24.6 b	1.25 c	0.19 b	2.31 c
		3541			27.2 a	1.53 a	0.24 a	2.76 b
Main effect of soil moisture			48		21.4 b	1.06 b	0.18 b	2.50 b
			100		30.7 a	1.85 a	0.28 a	2.90 a
Main effect of temperature				15	14.1 b	0.70 b	0.11 b	1.65 b
				25	38.0 a	2.21 a	0.35 a	3.76 a

^a Means within a column within a main effect group with a common letter are not significantly different at the 5% level by the Duncan's multiple range test.

planting (Table 3). However, after 33 days, significant visual injury was evident (Table 3). Trifluralin injury on the corn shoot (Table 4) and root lengths and weights (Table 5) are more clearly demonstrated. Shoot and root lengths, fresh and dry weights of the controls are significantly greater than the 0.22 kg/ha trifluralin-treated plants (Tables 4 and 5). The addition of 112 kg/ha of phosphorus resulted in an increase in corn injury in the main effects data averaged across hybrids and alachlor treatments (Table 3). This phosphorus addition also caused heavier shoots, but lighter roots in the main effects data in Tables 4 and 5. Differences due to the addition of phosphorus appeared to be caused more by a phosphorus-alachlor interaction, rather than a phosphorus-trifluralin interaction based on the injury ratings shown in Table 3.

The main effects data in Table 3 show that the 3.36 kg/ha rate of alachlor caused slight but significant visual injury to the corn and also significantly reduced the lengths and weights of corn shoots and roots (Tables 4 and 5). Pioneer 3747 was more tolerant than Pioneer 3572 to both trifluralin and alachlor (Tables 4 and 5).

Genetic variability. The 13 corn hybrids displayed a range of responses to trifluralin depending on the plant part or parameter examined (Table 6). The main effects data for this experiment are shown in Table 6 and the interaction data are found in the appendix (Table A3). Trifluralin at 0.45 kg/ha significantly reduced all growth parameters compared to the controls. The addition of phosphorus at 112 kg/ha resulted in significantly longer and heavier shoots and heavier roots than the controls. There was not a

Table 3. Visual injury ratings on plant shoots of two Pioneer corn hybrids treated with combinations of trifluralin, alachlor, and phosphorus.^a

Effects to be compared	Trifluralin (kg/ha)	Phosphorus as P ₂ O ₅ (kg/ha)	Alachlor (kg/ha)	Pioneer hybrid	Injury rating ^b	
					20 days ^c	33 days
Interaction	0	0	0	3747	0.0 e	0.0 e
				3572	0.3 e	0.0 e
				3747	0.3 e	0.3 e
				3572	0.8 cde	0.6 de
		112	0	3747	0.0 e	0.0 e
				3572	0.4 de	0.0 e
				3747	1.5 bc	1.1 cd
				3572	2.4 a	1.8 abc
	0.22	0	0	3747	0.4 de	1.4 bc
				3572	0.4 de	1.2 bc
				3747	1.1 bcd	1.5 bc
				3572	0.8 cde	1.5 bc
		112	0	3747	0.6 de	1.8 abc
				3572	0.4 de	1.8 abc
				3747	1.6 b	2.4 a
				3572	1.2 bcd	2.0 ab

Table 3. (Continued)

Effects to be compared	Trifluralin (kg/ha)	Phosphorus as P ₂ O ₅ (kg/ha)	Alachlor (kg/ha)	Pioneer hybrid	Injury rating	
					20 days	33 days
Main effect of trifluralin	0 0.22				0.7 a 0.8 a	0.5 b 1.9 a
Main effect of phosphorus		0 112			0.5 b 1.0 a	0.9 b 1.5 a
Main effect of alachlor			0 3.36		0.3 b 1.2 a	0.9 b 1.6 a
Main effect of hybrid				3747 3572	0.7 a 0.8 a	1.2 a 1.2 a

a Means within an analysis group within a column with a common letter are not significantly different at the 5% level by Duncan's multiple range test.

b Rating 0 equals no injury; 10 equals death of plant.

c Rating is given for the number of days after planting.

Table 4. The interaction of trifluralin, phosphorus, and alachlor on the shoots of two Pioneer corn hybrids.^a

Effects to be compared	Trifluralin (kg/ha)	Phosphorus as P ₂ O ₅ (kg/ha)	Alachlor (kg/ha)	Pioneer hybrid	Shoot		
					Length (cm)	fresh wt (g)	dry wt (g)
Interaction	0	0	0	3747	31.0 bc	2.5 c	.47 bc
				3572	27.8 de	1.9 ef	.35 ef
				3747	28.7 cde	2.1 de	.46 bc
				3572	25.3 f	1.6 f	.32 fg
		112	0	3747	34.7 a	3.3 a	.68 a
				3572	32.2 b	2.8 b	.52 b
				3747	28.0 de	2.4 cd	.49 b
				3572	24.8 fg	1.8 ef	.36 ef
	0.22	0	0	3747	30.3 bcd	2.0 de	.48 bc
				3572	22.8 gh	1.2 g	.26 g
				3747	26.9 ef	1.7 ef	.41 cde
				3572	21.5 h	1.2 g	.26 g
		112	0	3747	28.8 cde	1.9 ef	.45 bcd
				3572	21.2 h	1.2 g	.27 g
				3747	26.5 ef	1.5 f	.38 def
				3572	20.6 h	1.0 g	.27 g
Main effect of trifluralin	0				29.1 a	2.3 a	.46 a
	0.22				24.9 b	1.5 b	.35 b
Main effect of phosphorus		0			26.8 a	1.8 b	.38 b
		112			27.2 a	2.0 a	.43 a
Main effect of alachlor			0		28.7 a	2.1 a	.43 a
			3.36		25.3 b	1.7 b	.37 b

Table 4. (Continued)

Effects to be compared	Trifluralin (kg/ha)	Phosphorus as P ₂ O ₅ (kg/ha)	Alachlor (kg/ha)	Pioneer hybrid	Shoot		
					length (cm)	fresh wt (g)	dry wt (g)
Main effect of hybrid				3747	29.4 a	2.2 a	.48 a
				3572	24.6 b	1.6 b	.32 b

a Means within an analysis group within a column with a common letter are not significantly different at the 5% level by Duncan's multiple range test.

Table 5. The interaction of trifluralin, phosphorus, and alachlor on the roots of two Pioneer corn hybrids.^a

Effects to be compared	Trifluralin (kg/ha)	Phosphorus as P ₂ O ₅ (kg/ha)	Alachlor (kg/ha)	Pioneer hybrids	Root		
					length (cm)	fresh wt (g)	dry wt (g)
Interaction	0	0	0	3747	42.6 abc	7.2 b	.51 abc
				3572	46.2 a	6.2 c	.46 a-e
				3747	37.9 a	7.6 ab	.55 a
		112	0	3572	40.4 bc	5.2 d	.39 def
				3747	41.7 abc	8.3 a	.52 ab
				3572	41.8 abc	7.1 b	.43 b-e
	0.22	0	3.36	3747	42.5 abc	7.0 bc	.45 b-e
				3572	44.9 ab	5.2 d	.33 fgh
				3747	9.5 de	4.9 de	.49 a-d
		112	0	3572	13.2 d	3.7 fgh	.41 c-f
				3747	9.7 de	4.1 efg	.40 def
				3572	8.9 de	3.4 fgh	.36 efg
		0	0	3747	9.4 de	4.3 def	.32 fgh
				3572	10.5 de	3.2 gh	.26 fgh
		3.36	3.36	3747	7.6 de	3.4 fgh	.27 gh
				3572	7.4 e	2.8 h	.26 h

Table 5. (Continued)

Effects to be compared	Trifluralin (kg/ha)	Phosphorus as P ₂ O ₅ (kg/ha)	Alachlor (kg/ha)	Pioneer hybrid	Root	
					length (cm)	fresh wt (g) dry wt (g)
Main effect of trifluralin	0				42.3 a	6.7 a .45 a
	0.22				39.5 b	3.7 b .35 b
Main effect of phosphorus		0			26.0 a	5.3 a .45 a
		112			25.7 a	5.2 a .35 b
Main effect of alachlor			0		26.8 a	5.6 a .42 a
			3.36		24.9 b	4.8 b .38 b
Main effect of hybrid				3747	25.1 a	5.9 a .44 a
				3572	26.7 a	4.6 b .36 b

a Means within an analysis group within a column with a common letter are not significantly different at the 5% level by Duncan's multiple range test.

Table 6. The main effects of trifluralin and phosphorus fertilizer on thirteen corn hybrids.^a

Effects to be compared	Trifluralin (kg/ha)	Phosphorus as P ₂ O ₅ (kg/ha)	Hybrid ^b	Shoot		Root	
				length (cm)	fresh wt (g)	length (cm)	fresh wt (g)
Main effect of trifluralin	0			26.9 a	2.4 a	52.3 a	9.3 a
	0.45			19.9 b	1.4 b	7.3 b	4.4 b
Main effect of phosphorus		0		23.1 b	1.8 b	29.9 a	6.5 b
		112		23.7 a	2.0 a	29.7 a	7.3 a
Main effect of hybrid			3901	23.9 b	2.0 b	31.1 ab	7.0 bc
			3184	24.2 b	1.9 bcd	28.1 de	6.9 bc
			SPX 49	22.6 c	1.8 cd	25.0 f	6.0 c
			3732	24.1 b	2.0 b	27.4 ef	6.5 bc
			3747	25.1 b	2.2 ab	28.2 cde	6.7 bc
			3186	21.1 de	1.8 cd	30.6 a-d	7.3 ab
			3541	24.8 b	2.1 b	32.4 ab	7.3 ab
			3535	26.8 a	2.4 a	30.7 a-d	7.2 b
			3320	24.5 b	2.0 b	32.3 ab	8.2 a
			3572	22.3 cd	1.7 cd	29.8 b-e	6.6 bc
			3382	21.6 cde	1.7 cd	27.6 ef	7.2 b
			x-6362	22.6 c	1.7 cd	33.0 a	6.1 c
			x-7382	20.9 e	1.6 d	31.0 abc	6.7 bc

^a Means within a column within a main effect group with a common letter are not significantly different at the 5% level by the Duncan's multiple range test.

^b With the exception of SPX 49, a Migro hybrid, all are Pioneer hybrids.

phosphorus-trifluralin interaction in this experiment. There were significant growth differences among the hybrids in the absence of trifluralin (Table A3). The 0.45 kg/ha trifluralin treatment appeared to limit plant growth so that the differences among lines disappeared (Table 6). This could be interpreted as trifluralin causing the greatest growth inhibition to the hybrids showing the greatest growth.

DISCUSSION

The degree of trifluralin tolerance displayed by a particular corn hybrid is dependent upon the environmental conditions under which the test was conducted. The first study showed that temperature was a more definitive modifier of trifluralin injury than soil moisture levels, but that both could be important depending on the response of a particular hybrid to specific conditions. This study tested only two levels of each factor, however, a much more complex situation exists in the field. Much of the trifluralin research reported in the literature deals with tests on only one variety or one plant species under one set of environmental conditions, or with field conditions that change from year to year. This may explain some of the confusing differences found in the literature concerning trifluralin effects on plants. By changing one factor, such as temperature from 15 C to 25 C, one could conclude that a hybrid was tolerant rather than susceptible to trifluralin. A change in the variety or hybrid used for the research could also result in a different conclusion.

The response of corn to the addition of both phosphorus and trifluralin showed no consistent pattern of interaction, which is in agreement with the report of Rahman et al. (39). A more definitive case can be made for a phosphorus-alachlor interaction, a serendipitous discovery that needs to be more thoroughly researched.

Bucholtz and Lavy (7) reported that both alachlor and trifluralin protected oats from photosynthesis inhibiting herbicides by inhibiting root growth, thereby reducing absorption of these herbicides. In the present study, alachlor reduced corn root and shoot growth and this effect was additive with trifluralin effects on corn. This conclusion is in agreement with the results of other researchers who tested for interactions of linuron, diuron, or dichlobenil with trifluralin (22, 28).

Significant differences were found in the tolerance of a range of corn hybrids to trifluralin. Pioneer 3572 was sensitive to trifluralin while Pioneer 3747 was tolerant. This genetic variability is in agreement with the findings of Davis et al. (13), who found from 0 to 70% injury to a range of corn hybrids and inbred lines to 0.56 kg/ha trifluralin in a field study. In the present study, the trifluralin was incorporated throughout the total soil volume of the pot, thus the corn roots were not able to escape the herbicide. In the field, herbicide residues would likely be in the top two or three inches of soil only, thus corn roots could penetrate this layer and escape injury. Differences in tolerance of hybrids to trifluralin were found in experiments with corn grown in pots when compared to field reports from Eli Lilly and Company. This difference would suggest two different mechanisms for tolerance -

physiological tolerance when the roots are confined to trifluralin-treated soil and morphological tolerance, or the ability to escape the herbicide by growing through and away from it, as in the field. Corn could have varying degrees of both types of tolerance.

A study of the tolerance of 113 flax (Linum usitatissimum L.) lines to trifluralin revealed similar results (34). Field results and greenhouse results were significant. However, no consistent relationship was noted between field and greenhouse results. Different rates of trifluralin resulted in differential responses of the lines. Since differences were detected in all tests, the author suggested that field tolerance was a function of more than one mechanism.

When the variability in tolerance of corn is combined with the specific responses of hybrids to trifluralin in different environmental conditions, a very complicated problem of predicting field responses becomes apparent. At the same time, the potential for improvement is also apparent. If corn hybrids and inbred lines can be identified that have several mechanisms of trifluralin tolerance, perhaps a fully tolerant corn hybrid can be produced by crossing that will solve the problem of injury due to trifluralin carry-over.

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CHAPTER 3

DIFFERENTIAL TOLERANCE RESPONSES OF CORN INBREDS AND HYBRIDS TO TWO INCORPORATION DEPTHS OF TRIFLURALIN

Abstract. Publically available corn (Zea mays L.) inbred lines (108) and hybrids (5) were evaluated for variability in tolerance to trifluralin (a,a,a,-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine) in field studies in 1982 and 1983. Furthermore, the influence of depth of trifluralin incorporation into the soil on corn tolerance was examined. The treatments were 0 kg/ha trifluralin double disked to a 15 cm depth, 0.56 kg/ha trifluralin incorporated to a 7.5 cm depth with a Kongskilde danish tine seed bed conditioner, and 0.56 kg/ha trifluralin incorporated to a 15 cm depth by double disking. All plots received preemergence applications of 2.24 kg/ha of both simazine [2-chloro-4,6-bis(ethylamino)-s-triazine] and alachlor [2-chloro-2',6'-diethyl-N-(methoxymethyl)acetanilide]. Trifluralin visual injury to corn, plant stand, shoot height and percent stunting were evaluated. The inbred lines showed from 10 to 90 percent visual injury while the hybrids ranged from 5 to 30 percent visual injury in response to the trifluralin treatments. Incorporation of trifluralin to 7.5 cm resulted in stand reduction, while 15 cm trifluralin incorporation resulted in reduction of shoot height and increased stunting. Early maturing inbreds showed greater injury than later maturing lines. Responses of the corn inbred lines and hybrids to

the two incorporation depths suggest at least two mechanisms for corn tolerance to trifluralin.

INTRODUCTION

Incorporation of trifluralin into the soil is recommended to position the herbicide in proximity to germinating weed seeds and to prevent loss of herbicidal activity by photodecomposition and volatilization (20). Depth of incorporation is one of the more important factors determining the degree of trifluralin root injury to plants (16). Cotton (Gossypium hirsutum L.) and soybean (Glycine max (L.) Merr.) lateral roots were inhibited to the depth of trifluralin incorporation (16). Below the trifluralin incorporation depth, cotton roots rapidly increased in number, suggesting a compensation effect (16).

Corn root elongation is inhibited by trifluralin (9,13). Since corn roots remain in the upper 7.5 to 15 cm of soil until the plant has its seventh or eighth leaf (2), they are particularly sensitive to varying trifluralin incorporation depths and carry-over trifluralin residues.

Trifluralin is relatively nonpersistent in soil, with dissipation of most of the biological activity occurring within six months in warm, humid climates (16, 17, 19). However, trifluralin persistence increases with decreasing soil temperature and moisture content and carry-over to subsequent crops can occur (10). Increasing depth of trifluralin incorporation increases persistence (16, 20).

Trifluralin carry-over injury to corn grown after soybeans has been

reported (6) and the problem is likely to increase as conservation tillage becomes more widely used. Moldboard plowing places the trifluralin concentration below the zone of maximum phytotoxicity which does not occur with conservation tillage (3, 4, 6, 12).

Davis et al. (5) tested 18 parental lines and 34 single crosses of corn for tolerance to 0.56 kg/ha trifluralin. The corn showed from 0 to 70 percent injury in response to the trifluralin. Differential responses of inbred and hybrid corn have been reported for several herbicides other than trifluralin (1, 7, 8, 15, 18). These findings support the conclusion reached in Chapter 2 of this thesis that significant differences in genetic tolerance to trifluralin exist in 13 corn hybrids. To test the hypothesis developed in Chapter 2 that there are at least two mechanisms involved in trifluralin tolerance, physiological tolerance and morphological tolerance, a field study with a wider range of genetic material was most appropriate. Shallow incorporation would allow corn inbred lines and hybrids with rapid downward root growth to escape injury quickly, while deep incorporation would select for inbred lines and hybrids with physiological tolerance.

The objective of this study was to evaluate the tolerance of 108 corn inbred lines and 5 hybrids to trifluralin incorporated at two depths and determine if two mechanisms of trifluralin tolerance exist.

MATERIALS AND METHODS

Field experiments were conducted in 1982 and 1983 at East Lansing, Michigan on a Capac loam (Aeric Ochraqualf fine-loamy, mixed, mesic) with a pH of 7.0 and 2.1% organic matter content. The 1983 location was in the same field, but a different area than 1982, to avoid potential trifluralin carry-over injury. The same corn inbred lines (108) and hybrids (5) were evaluated each year. Inbred seed was obtained in 1982 from the Inter-Regional Maize Inbred Evaluation (IRMIE) trial. The inbred lines were hand-pollinated at another location in 1982 to produce seed for 1983 experiments. A list of the inbred lines included in this study is given in Table 1. A list of the hybrids can be found in Table 3.

Treatments of 0 or 0.56 kg/ha trifluralin were applied to the soil surface with a tractor-mounted sprayer at 215 L/ha and incorporated 7.5 cm deep with one pass of a Kongskilde danish tine seed bed conditioner or 15 cm deep with two passes of a tandem disk. The control plots were disked twice to produce the same level of soil compaction. A topdressing of 168 kg/ha of triple superphosphate was made each year prior to herbicide application. Carbofuran¹ (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) was applied at 11.2 kg/ha over the row with a corn planter as the rows were marked prior to hand-planting for corn rootworm control. At the same time, a 10-20-20 analysis fertilizer was banded next to the row at 224 kg/ha in 1982 and 202 kg/ha in 1983.

¹ FURADAN (10G)

The rows were 4.6 m long and 91 cm apart with 30 seeds per row. The rows were hand-planted on May 14, 1982 and May 12, 1983. Weed control each year consisted of 2.24 kg/ha simazine plus 2.24 kg/ha alachlor applied preemergence. Anhydrous ammonia was applied during the growing season at 134 kg/ha in 1983. The study was irrigated by overhead sprinklers as needed both years.

Plant stand, shoot height, injury, and stunting were evaluated at appropriate intervals each year. These measurements were used to calculate a trifluralin tolerance index for the inbred lines and hybrids. The equation used to calculate the index value was:

Trifluralin Tolerance

$$\text{Index Value} = [100 \times A \times (1-B) \times C \times (1-D) \times E]$$

where for 7.5 cm trifluralin incorporation depth:

- A = early season plant stand mean as a percent of control
- B = stunting percent mean minus the control stunting percent mean
- C = early season shoot height mean as a percent of control
- D = early season injury mean minus the control injury mean
- E = late season control plant stand percent mean

or for 15 cm trifluralin incorporation depth:

- A = late season plant stand mean as a percent of control
- B = stunting percent mean minus the control stunting percent mean
- C = late season shoot height mean as a percent control
- D = late season injury mean minus the control injury mean
- E = late season control plant stand percent mean.

This index is an attempt to quantify injury for each inbred line or hybrid for comparison purposes.

The experimental design was a split-plot with four replications. Data were subjected to analysis of variance and the means separated either by the Duncan's multiple range test or the LSD test.

Complete data on the 108 inbred lines are too voluminous to be included, and are available from the author. The inbred data are presented as the main effects, while the hybrid data presented are means and main effects.

RESULTS

Trifluralin at 0.56 kg/ha incorporated to a depth of 7.5 cm caused a significant reduction in inbred corn stand in both years (Table 2). Inbred stand reduction was greater in 1983 than 1982, likely due to hot and dry conditions. There was a tendency for the early maturing inbreds to show a greater reduction in stand from the trifluralin treatment (Table 2).

Trifluralin at 0.56 kg/ha incorporated to a depth of 7.5 cm also caused a significant reduction in hybrid corn stand in 1982 when averaged over all hybrids (Table 3). In 1983, the 15 cm deep incorporation of trifluralin caused a significant stand reduction compared to the control when averaged over all the hybrids, but was not different from the 7.5 cm incorporated treatment. Pioneer 3320 showed the greatest stand reduction in 1982 when averaged over all trifluralin treatments, while Pioneer 3747 had the least (Table 3). Trifluralin incorporated to 7.5 cm caused greater stand reduction of

Table 1. Inbred corn line numbers and codes from the 1982 IRMIE entry list that were used in the trifluralin residue field studies.

Relative Maturity					
Early - Group 13 ^a		Middle - Group 46		Late - Group 78	
Line		Line		Line	
Number	Code	Number	Code	Number	Code
1	CN105+ ^b	37	A619+	77	B73+
2	C0109+	38	A632+	78	M017+
3	A661	39	B85	79	N28HT+
4	A665	40	A634	80	B68
5	A666	41	A635	81	B75
6	A671	42	A659	82	B76
7	ND100	43	A670	83	B77
8	ND240	44	M042	84	B79
9	ND241	45	AY499	85	B84
10	ND245	46	AY562	86	M014W
11	ND246	47	NY378	87	M020W
12	ND300	48	NY821 LERF	88	M040
13	ND301	49	NYD410	89	M042
14	ND376	50	NYRW3	90	N132
15	ND408	51	NYRW20	91	N139
16	ND474	52	NYRW23	92	N152
17	PA326	53	PA405	93	CH509A
18	PA329	54	FR19	94	CH514
19	PA373	55	CH9	95	PA91
20	PA374	56	CH581-13	96	PA762
21	CK52	57	CH586-12	97	PA871
22	CK64	58	CH591-36	98	PA872
23	CK69	59	CH592-46	99	FR16
24	CK75	60	CH593-9	100	FR20
25	CG11	61	CH606-11	101	FR21
26	CG12	62	CH663-8	102	H60
27	CG13	63	B87	103	H84
28	CG14	64	MS71	104	H93
29	CG15	65	MS75	105	H98
30	CG16	66	MS76	106	H100
31	CG17	67	MS200	107	H102
32	CG18	68	H95	108	H103
33	CL1	69	H99		
34	MS72	70	W64A+		
35	MS74	71	W548		
36	W117HT+	72	W552C		
		73	W562		
		74	W570		
		75	CH753-4		
		76	CH671-28		

^a Maturity based on southern Michigan growing conditions.

^b + represents a check entry, an established line used for maturity placement.

Table 2. Plant stand response of inbred corn lines to trifluralin treatments in 1982 and 1983 field studies.

Trifluralin treatment (kg/ha)	Incorporation depth (cm)	Maturity group	1982			1983	
			June 9	July 14	July 6	August 8	
			—(%)—			—(%)—	
0.00	15.0	13	76.6 ^a	74.9	67.0	65.5	
		46	80.1	79.3	71.2	70.4	
		78	77.1	76.1	69.9	68.5	
0.56	7.5	13	52.3 ^{**b}	50.0 ^{**}	47.6	46.8	
		46	56.4 ^{**}	53.2 ^{**}	47.5 [*]	47.1 [*]	
		78	66.2	62.8	46.8 [*]	46.0 [*]	
0.56	15.0	13	71.6	69.0	43.7 [*]	42.9 [*]	
		46	83.2	79.5	53.0	51.6	
		78	72.7	70.2	54.9	54.1	
Main effect ($\bar{x}$)							
0.00	15.0		78.1	76.9	69.4	68.1	
0.56	7.5		58.0 [*]	54.4 [*]	47.3 [*]	46.6 [*]	
0.56	15.0		76.2	73.2	50.5	49.6	
LSD							
(0.05)			15.6	15.4	20.3	20.3	
(0.01)			20.6	20.3	26.7	26.7	

^a Means are averaged over 36 lines for group 13, 40 lines for group 46, or 32 lines for group 78.

^b Means for a given date or main effect are significantly different at the 5% level by the LSD test if marked with an *; at the 1% level if marked with an **.

Table 3. Plant stand response of Pioneer corn hybrids to trifluralin treatments in 1982 and 1983 field studies.^a

1982									
Pioneer hybrid	June 9			July 14					
	Trifluralin treatment (0.56 kg/ha)			Trifluralin treatments (0.56 kg/ha)					
	Control	7.5 cm	15 cm	Control	7.5 cm	15 cm	Main effect		
	------(%)-----			------(%)-----			------(%)-----		
	(X̄)			(X̄)			(X̄)		
3747	93.3 ab	90.0 abc	96.7 a	93.3 a	88.3 ab	95.0 a	91.4 a		
3572	92.5 ab	85.0 bcd	91.7 ab	89.7 ab	85.0 ab	85.8 ab	88.1 ab		
3320	86.7 abc	75.8 d	93.3 ab	85.3 b	72.5 c	90.0 ab	85.0 b		
3541	87.5 abc	86.7 abc	94.2 ab	89.4 ab	85.0 ab	95.0 a	89.2 ab		
3382	95.8 ab	80.8 cd	92.5 ab	89.7 ab	80.8 bc	90.0 ab	88.3 ab		
Main effect									
(X̄)	91.2 a	83.7 b	93.7 a	91.7 a	82.3 b	91.2 a			
1983									
Pioneer hybrid	July 6			August 8					
	Trifluralin treatment (0.56 kg/ha)			Trifluralin treatments (0.56 kg/ha)					
	Control	7.5 cm	15 cm	Control	7.5 cm	15 cm	Main effect		
3747	94.2 ab	94.2 ab	90.0 abc	92.8 a	91.7 ab	88.3 abc	90.8 a		
3572	87.5 abc	81.7 b-e	79.2 cde	82.8 b	87.5 abc	77.5 cde	81.9 b		
3320	97.5 a	91.7 abc	95.8 a	95.0 a	91.7 ab	95.0 a	94.2 a		
3541	82.5 bcd	81.7 b-e	69.2 e	77.8 b	80.8 bcd	68.3 e	76.7 b		
3382	94.2 ab	82.5 bcd	74.2 de	83.6 b	92.5 ab	73.3 de	81.9 b		
Main effect									
(X̄)	91.2 a	86.3 ab	81.7 b	89.7 a	85.2 ab	80.5 b			

^a Means for a data set for a given year and date or main effect with a common letter are not significantly different at the 5% level by the Duncan's multiple range test.

Pioneer 3320 in 1982 than the 15 cm incorporation. In 1983, Pioneer 3320 and Pioneer 3747 were statistically the same in stand reduction, and both had greater stands than the other hybrids when averaged over all treatments (Table 3).

Inbred corn lines did not show a significant shoot height response to trifluralin at either incorporation depth when expressed as a percent of control (Table 4). There was a tendency for a greater reduction in shoot height by the trifluralin at the 15 cm incorporation depth (Table 4).

Shoot height was significantly reduced both years by the incorporation of 0.56 kg/ha of trifluralin to 15 cm when expressed as a percent of control and averaged over all hybrids (Table 5). Individual hybrids did not show significant responses to trifluralin at either incorporation depth. Inhibition of shoot height tended to decrease as the season progressed for the hybrids (Table 5) and the inbred lines (Table 4), suggesting recovery from early trifluralin injury.

Trifluralin at 0.56 kg/ha at both incorporation depths significantly injured all inbred lines both years as measured by visual injury (Table 6). The early maturity group was injured the most of the three maturity groups and the injury persisted later in the season. Overall trifluralin injury decreased as the season progressed both years (Table 6).

Visual injury to the corn hybrids by 0.56 kg/ha trifluralin at both incorporation depths was significant both years averaged over all hybrids (Table 7). Trifluralin incorporated at both depths visually injured the hybrids to the same degree in 1982. In 1983,

Table 4. Plant shoot height response of inbred corn lines to trifluralin treatments in 1982 and 1983 field studies.

Trifluralin treatment (kg/ha)	Incorporation depth (cm)	Maturity group	1982			1983	
			June 22 ---(% of control)---	July 19 -----	July 5 ---(% of control)---	August 4	
0.56	7.5	13	66.0 ^a	70.5	66.6	87.6	
		46	75.3	79.4	66.6	81.8	
		78	76.1	78.7	66.2	78.0	
0.56	15.0	13	63.3	67.1	58.7	78.5	
		46	66.1	70.8	63.0	77.7	
		78	62.8	71.1	62.8	76.4	
Main effect ($\bar{X}$)							
0.56	7.5		72.5	76.2	66.5	82.5	
0.56	15.0		64.1	69.7	61.5	77.5	
LSD							
(0.05)			21.5	20.1	30.7	28.8	
(0.01)			28.3	26.4	40.4	37.9	

^a Means are averaged over 36 lines for group 13, 40 lines for group 46, or 32 lines for group 78.

Table 5. Plant shoot height response of Pioneer corn hybrids to trifluralin treatments in 1982 and 1983 field studies.^a

1982		June 22		July 19	
Pioneer hybrid	Trifluralin treatment (0.56 kg/ha)		Trifluralin treatments (0.56 kg/ha)		Main effect
	7.5 cm	15 cm	7.5 cm	15 cm	
	-----(% of control)-----		-----(% of control)-----		
	(X̄)		(X̄)		
3747	85.5 a	65.8 a	75.6 a	79.2 b	86.8 ab
3572	79.5 a	80.4 a	79.9 a	92.2 ab	93.8 a
3320	68.6 a	80.2 a	74.4 a	83.1 ab	86.7 ab
3541	90.5 a	84.6 a	87.5 a	87.5 ab	90.3 ab
3382	90.6 a	85.4 a	88.0 a	83.3 ab	84.7 b
Main effect	82.9 a	79.2 a	91.9 a	85.1 b	
	(X̄)				
Pioneer hybrid	July 5		August 4		
	1983				
	(X̄)				
3747	97.8 ab	81.6 ab	94.3 abc	82.3 bc	88.3 a
3572	89.5 ab	70.8 ab	92.9 abc	83.7 abc	88.3 a
3320	87.2 ab	68.0 b	90.5 abc	81.7 c	86.1 a
3541	98.7 a	80.5 ab	96.4 a	89.1 abc	92.7 a
3382	84.6 ab	81.1 ab	95.1 ab	87.2 abc	91.1 a
Main effect	91.5 a	76.4 b	93.8 a	84.8 b	
	(X̄)				

a Means for a data set for a given year and date or main effect with a common letter are not significantly different at the 5% level by the Duncan's multiple range test.

Table 6. Visual injury response of inbred corn lines to trifluralin treatments in 1982 and 1983 field studies.

Trifluralin treatment (kg/ha)	Incorporation depth (cm)	Maturity group	1982			1983		
			June 9	July 14	August 17	July 6	August 1	August 24
			(% injury)			(% injury)		
0.00	15.0	13	12.0 ^a	10.7	4.7	1.7	1.1	1.4
		46	5.1	3.8	0.8	2.6	1.8	1.1
		78	7.3	4.5	0.9	2.0	2.3	0.6
0.56	7.5	13	51.6 ^{**b}	43.3 ^{**}	23.2 ^{**}	31.4 ^{**}	28.4 ^{**}	17.6
		46	44.9 ^{**}	29.3 ^{**}	12.2	33.1 ^{**}	24.8 [*]	14.0
		78	45.8 ^{**}	33.6 ^{**}	8.7	33.4 ^{**}	23.9 [*]	14.0
0.56	15.0	13	40.9 ^{**}	43.3 ^{**}	25.4 ^{**}	37.5 ^{**}	37.2 ^{**}	28.4 ^{**}
		46	35.9 ^{**}	33.5 ^{**}	12.2	35.4 ^{**}	27.2 [*]	15.8
		78	33.3 ^{**}	36.7 ^{**}	9.9	34.9 ^{**}	24.9 [*]	10.6
Main effect ($\bar{X}$)								
0.00	15.0		8.0	6.3	2.1	2.1	1.7	1.1
0.56	7.5		47.0 ^{**}	35.2 ^{**}	14.1 [*]	32.7 ^{**}	25.7 [*]	16.0
0.56	15.0		36.7 ^{**}	38.5 ^{**}	15.9 [*]	35.9 ^{**}	29.8 ^{**}	19.8 [*]
LSD								
(0.05)			14.2	17.2	11.6	17.9	19.8	18.6
(0.01)			18.7	22.6	15.3	23.6	26.1	24.4

^a Means are averaged over 36 lines for group 13, 40 lines for group 46, or 32 lines for group 78.

^b Means for a given date or main effect are significantly different at the 5% level by the LSD test if marked with an *; at the 1% level if marked with an **.

Table 7. Visual injury response of Pioneer corn hybrids to trifluralin treatments in 1982 and 1983 field studies.^a

1982											
June 9						July 14					
Pioneer hybrid	Trifluralin treatment (0.56 kg/ha)			Main effect	Trifluralin treatments (0.56 kg/ha)			Main effect			
	Control	7.5 cm	15 cm		Control	7.5 cm	15 cm				
	——(% injury)——				——(% injury)——						
			($\bar{X}$)				($\bar{X}$)				($\bar{X}$)
3747	0.0 d	20.0 b	23.8 ab	14.6 ab	0.0 b	0.0 b	5.0 b	0.0 b	0.0 b	5.0 b	1.7 b
3572	0.0 d	22.5 ab	15.0 bc	12.5 b	0.0 b	2.5 b	2.5 b	0.0 b	2.5 b	2.5 b	1.7 b
3320	1.3 d	30.0 a	23.8 ab	18.3 a	0.0 b	7.5 ab	12.5 a	0.0 b	7.5 ab	12.5 a	6.7 a
3541	0.0 d	8.8 cd	7.5 cd	5.4 c	0.0 b	2.5 b	0.0 b	0.0 b	2.5 b	0.0 b	0.8 b
3382	0.0 d	13.8 bc	7.5 cd	7.1 c	0.0 b	7.5 ab	5.0 b	0.0 b	7.5 ab	5.0 b	4.2 ab
Main effect											
($\bar{X}$)	0.3 b	19.0 a	15.5 a		0.0 b	4.0 a	5.0 a				
1983											
July 6						August 1					
Pioneer hybrid											
3747	0.0 d	5.0 cd	17.5 ab	7.5 a	0.0 d	5.0 cd	13.8 ab	0.0 d	5.0 cd	13.8 ab	6.3 a
3572	2.5 cd	12.5 abc	22.5 a	12.5 a	0.0 d	3.8 cd	12.5 ab	0.0 d	3.8 cd	12.5 ab	5.4 a
3320	0.0 d	16.3 ab	22.5 a	12.9 a	0.0 d	7.5 bc	16.3 a	0.0 d	7.5 bc	16.3 a	7.9 a
3541	2.5 cd	12.5 abc	17.5 ab	10.8 a	1.3 cd	3.8 cd	13.8 ab	1.3 cd	3.8 cd	13.8 ab	6.3 a
3382	0.0 d	10.0 bcd	12.5 abc	7.5 a	0.0 d	7.5 bc	17.5 a	0.0 d	7.5 bc	17.5 a	8.3 a
Main effect											
($\bar{X}$)	1.0 c	11.3 b	18.5 a		0.3 c	5.5 b	14.8 a				

Table 7. (Continued)

Pioneer hybrid	August 17, 1982			Main effect ($\bar{X}$)
	Trifluralin treatment (0.56 kg/ha)			
	Control	7.5 cm	15 cm	
	-----(% injury)-----			
	1982			
	No injury			
	1983			
	August 24, 1983			
3747	0.0 b	0.0 b	5.0 ab	1.7 a
3572	0.0 b	0.0 b	6.3 a	2.1 a
3320	0.0 b	1.3 ab	6.3 a	2.5 a
3541	0.0 b	0.0 b	5.0 ab	1.7 a
3382	0.0 b	1.3 ab	6.3 a	2.5 a
Main effect				
($\bar{X}$)	0.0 b	0.5 b	5.8 a	

a Means for a data set for a given year and date or main effect with a common letter are not significantly different at the 5% level by the Duncan's multiple range test.

trifluralin incorporated to the 15 cm depth caused significantly greater visual injury than at the 7.5 cm depth or the control when averaged over all hybrids (Table 7). Pioneer 3320 displayed the most visual injury in 1982 when averaged over all the trifluralin treatments, but there were no significant differences among the lines in 1983. There was a tendency for reduced visual injury as the season progressed both years (Table 7).

Inbred corn lines showed significant stunting with 0.56 kg/ha trifluralin incorporated to 15 cm in 1982 but not in 1983 (Table 8). The death of potential stunted plants due to the harsher environmental conditions in 1983, as shown in the lower stands in Table 2, possibly accounting in these results.

Trifluralin at 0.56 kg/ha at both incorporation depths significantly stunted the hybrid corn both years when averaged over all hybrids (Table 9). A slight, but significant, increase in stunting occurred when trifluralin was incorporated to 7.5 cm compared to the 15 cm in 1982. Pioneer 3320 had the largest percent of stunted plants both years, when averaged over all trifluralin treatments (Table 9).

Trifluralin tolerance index values for 1982 (Table 10) and 1983 (Table 11) show the wide tolerance range found in the 108 inbred lines. The relative rank of an individual inbred line varied between 1982 and 1983, apparently in response to the different environmental conditions of the two years. The tolerance index value of a given inbred line is dependent on the depth of trifluralin incorporation into the soil (Tables 10 and 11).

Table 8. Stunting response of inbred corn lines to trifluralin treatments in 1982 and 1983 field studies.^a

Trifluralin treatment (kg/ha)	Incorporation depth (cm)	Maturity group	August 17, 1982 —(% stunted)—	August 30, 1983 —(% stunted)—
0.00	15.0	13 46 78	2.2 ^b 1.6 2.90	2.7 1.4 2.0
0.56	7.5	13 46 78	8.1 6.3 8.9	5.5 4.8 5.1
0.56	15.0	13 46 78	12.6 ^{**c} 12.6 ^{**} 9.8	8.9 5.5 5.1
Main effect ($\bar{x}$)				
0.00	15.0		2.0	1.9
0.56	7.5		7.9	5.1
0.56	15.0		11.8*	6.5
LSD				
(0.05)			7.6	18.5
(0.01)			10.0	24.3

^a Stunting was evaluated as the percent of the corn plants that were less than 50 percent as tall as the average for the particular inbred line.

^b Means are averaged over 36 lines for group 13, 40 lines for group 46, or 32 lines for group 78.

^c Means for a given date or main effect are significantly different at the 5% level by the LSD test if marked with an *; at the 1% level if marked with an **.

Table 9. Stunting response of Pioneer corn hybrids to trifluralin treatments in 1982 and 1983 field studies.^a

Pioneer hybrid	August 17, 1982			
	Trifluralin treatment (0.56 kg/ha)			Main effect
	Control	7.5 cm	15 cm	
	----- (%) -----			($\bar{X}$)
3747	0.0 db	6.7 b	1.7 cd	2.8 b
3572	0.8 cd	6.7 b	5.0 bc	4.2 b
3320	0.8 cd	12.5 a	12.5 a	8.6 a
3541	1.7 cd	2.5 bcd	2.5 bcd	2.2 b
3382	0.0 d	6.7 b	4.2 bcd	3.6 b
Main effect				
($\bar{X}$)	0.7 c	7.0 a	5.7 b	
Pioneer hybrid	August 30, 1983			
3747	0.8 e	8.3 a-d	8.3 a-d	5.8 ab
3572	2.5 cde	7.5 a-e	5.0 a-e	5.0 ab
3320	1.7 de	10.8 ab	9.2 abc	7.2 a
3541	0.8 e	4.2 b-e	1.7 de	2.2 b
3382	1.7 de	11.7 a	5.8 a-e	6.4 a
Main effect				
($\bar{X}$)	1.5 b	8.5 a	6.0 a	

^a Stunting was evaluated as the percent of the corn plants that were less than 50 percent as tall as the average for the particular hybrid.

^b Means for a data set for a given year and date or main effect with a common letter are not significantly different at the 5% level by the Duncan's multiple range test.

Table 10. Ranking of tolerance index values of inbred corn lines that were treated with 0.56 kg/ha trifluralin at two incorporation depths in a 1982 field study.^a

Inbred Line	Code ^b	Incorporation depth 7.5 cm	Inbred Line	Code	Incorporation depth 15.0 cm
19	PA373	0.21	19	PA373	1.49
5	A666	0.81	20	PA374	8.25
20	PA374	1.41	7	ND100	16.73
36	W117HT+C	5.64	98	PA872	17.15
18	PA329	6.04	8	ND240	18.95
57	CH586-12	8.43	9	ND241	19.69
16	ND474	9.17	18	PA329	21.30
15	ND408	9.60	29	CG15	21.90
68	H95	9.67	15	ND408	21.92
34	MS72	9.98	106	H100	22.64
48	NY821 LERF	10.09	36	W117HT+	23.36
35	MS74	12.67	35	MS74	24.44
99	FR16	12.75	45	AY499	25.26
50	NYRW3	13.09	16	ND474	25.90
24	CK75	13.51	47	NY378	26.30
25	CG11	13.69	88	M040	27.15
83	B77	13.86	5	A666	27.40
45	AY499	14.00	14	ND376	27.55
13	ND301	14.03	80	B68	27.62
29	CG15	14.75	97	PA871	29.35
2	CO109+	15.27	69	H99	29.87
86	MO14W	15.92	34	MS72	30.75
91	N139	15.94	4	A665	31.10
100	FR20	15.98	13	ND301	31.52
30	CG16	16.66	90	N132	31.80
95	PA91	16.84	2	CO109+	32.02
69	H99	16.98	71	W548	32.78
54	FR19	17.57	25	CG11	33.26
1	CN105+	17.75	102	H60	34.12
17	PA326	17.86	53	PA405	34.45
14	ND376	18.41	72	W552C	34.62
49	NYD410	18.49	10	ND245	34.83
55	CH9	18.63	24	CK75	34.86
27	CG13	18.72	37	A619+	35.28
31	CG17	19.03	31	CG17	35.42
59	CH592-46	19.26	33	CL1	35.64
53	PA405	19.39	74	W570	35.66
28	CG14	19.69	84	B79	35.77
88	M040	19.95	108	H103	35.96
71	W548	20.05	40	A634	36.70
41	A635	20.08	32	CG18	37.16
70	W64A+	20.20	41	A635	37.17
42	A659	20.87	28	CG14	37.45

Table 10. (Continued)

Inbred Line	Code	Incorporation depth 7.5 cm	Inbred Line	Code	Incorporation depth 15.0 cm
98	PA872	21.08	75	CH753-4	37.94
101	FR21	21.14	48	NY821 LERF	38.44
61	CH606-11	21.22	95	PA91	38.77
39	B85	21.68	73	W562	38.84
26	CG12	21.83	86	MO14W	38.90
52	NYRW23	22.27	27	CG13	38.93
7	ND100	22.30	62	CH663-8	38.96
102	H60	22.41	44	MO42	39.08
65	MS75	23.64	11	ND246	39.28
32	CG18	23.72	68	H95	39.45
73	W562	24.51	83	B77	39.48
107	H102	24.67	99	FR16	39.81
90	N132	24.79	101	FR21	40.13
9	ND241	24.91	26	CG12	40.47
64	MS71	25.03	55	CH9	41.49
4	A665	25.37	107	H102	42.03
38	A632+	25.38	54	FR19	42.52
105	H98	25.55	6	A671	43.25
97	PA871	25.64	3	A661	43.67
106	H100	25.81	60	CH593-9	43.69
51	NYRW20	25.84	67	MS200	43.70
72	W552C	26.27	49	NYD410	43.72
58	CH591-36	26.78	94	OH514	44.22
80	B68	26.78	85	B84	44.32
47	NY378	27.54	17	PA326	44.33
44	MO42	27.89	50	NYRW3	44.64
84	B79	27.92	79	N28HT+	45.06
79	N28HT+	28.25	39	B85	45.54
60	CH593-9	28.45	105	H98	45.68
33	CL1	28.48	38	A632+	45.75
63	B87	29.23	77	B73+	45.76
76	CH671-28	29.76	87	MO20W	46.29
75	CH753-4	29.87	91	N139	46.31
81	B75	30.13	23	CK69	46.48
94	OH514	31.11	82	B76	46.76
8	ND240	32.04	64	MS71	46.78
78	MO17+	33.07	42	A659	47.27
37	A619+	33.31	51	NYRW20	47.55
74	W570	34.77	100	FR20	47.56
6	A671	34.92	30	CG16	48.56
46	AY562	34.92	78	MO17+	49.17
103	H84	34.97	12	ND300	49.41
40	A634	35.14	58	CH591-36	49.52
77	B73+	35.51	59	CH592-46	50.03
89	MO42	35.75	46	AY562	50.28

Table 10. (Continued)

Inbred Line	Code	Incorporation depth 7.5 cm	Inbred Line	Code	Incorporation depth 15.0 cm
11	ND246	36.18	22	CK64	50.33
82	B76	36.29	81	B75	51.09
22	CK64	36.84	56	CH581-13	51.97
56	CH581-13	36.88	52	NYRW23	51.98
96	PA762	37.13	89	MO42	52.59
67	MS200	38.07	92	N152	53.19
66	MS76	38.70	96	PA762	53.98
23	CK69	39.15	1	CN105+	54.08
10	ND245	39.86	70	W64A+	58.06
43	A670	40.87	57	CH586-12	58.31
12	ND300	41.37	63	B87	58.45
62	CH663-8	41.60	61	CH606-11	59.54
108	H103	42.51	43	A670	60.45
93	CH509A	43.69	21	CK52	60.74
87	MO20W	43.79	76	CH671-28	61.13
104	H93	44.29	103	H84	63.18
3	A661	47.16	65	MS75	63.87
21	CK52	47.88	104	H93	64.39
92	N152	48.40	66	MS76	65.17
85	B84	60.72	93	CH509A	66.68

Main effect

($\bar{X}$)	24.99	40.29
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^a Value 0 equals lowest ranking; the higher the value, the better the inbred line performed.

^b Code is from the 1982 IRMIE trial.

^c + represents a check entry, an established line used for maturity placement.

Table 11. Ranking of tolerance index values of inbred corn lines that were treated with 0.56 kg/ha trifluralin at two incorporation depths in a 1983 field study.^a

Inbred Line ^b	Code ^c	Incorporation depth 7.5 cm	Inbred Line	Code	Incorporation depth 15.0 cm
22	CK64	1.07	22	CK64	0.16
107	H102	1.75	107	H102	0.87
80	B68	2.83	16	ND474	1.19
16	ND474	3.74	51	NYRW20	2.66
74	W570	4.07	80	B68	4.48
47	NY378	4.89	15	ND408	5.26
15	ND408	5.33	9	ND241	6.33
58	CH591-36	6.12	74	W570	6.91
23	CK69	6.41	47	NY378	9.69
57	CH586-12	7.36	23	CK69	10.08
68	H95	7.37	36	W117HT ⁺ d	10.31
94	CH514	7.47	8	ND240	10.61
51	NYRW20	8.09	52	NYRW23	12.01
59	CH592-46	8.38	7	ND100	13.39
88	MO40	9.48	14	ND376	14.72
91	N139	9.93	10	ND245	15.53
8	ND240	10.68	18	PA329	16.53
86	MO14W	10.73	27	CG13	16.99
13	ND301	11.45	12	ND300	17.26
97	PA871	11.77	11	ND246	18.13
60	CH593-9	12.02	45	AY499	18.92
36	W117HT ⁺	12.11	17	PA326	19.80
56	CH581-13	12.15	49	NYD410	19.93
24	CK75	12.29	61	CH606-11	21.28
95	PA91	12.68	54	FR19	21.63
52	NYRW23	12.76	13	ND301	22.19
54	FR19	13.23	34	MS72	23.20
27	CG13	13.65	86	MO14W	23.35
11	ND246	14.14	42	A659	23.76
9	ND241	14.55	48	NY821 LERF	24.02
50	NYRW3	14.78	60	CH593-9	24.18
61	CH606-11	14.81	69	H99	24.28
89	MO42	14.88	43	A670	24.61
7	ND100	15.75	24	CK75	24.71
96	PA762	16.53	57	CH586-12	25.56
99	FR16	16.54	19	PA373	25.86
92	N152	16.57	76	CH671-28	25.88
90	N132	16.72	21	CK52	26.11
76	CH671-28	16.88	25	CG11	26.57
55	CH9	16.89	55	CH9	26.72
87	MO20W	17.06	5	A666	26.82
48	NY821 LERF	17.90	90	N132	27.98
69	H99	18.05	6	A671	28.15

Table 11. (Continued)

Inbred Line	Code	Incorporation depth 7.5 cm	Inbred Line	Code	Incorporation depth 15.0 cm
5	A666	18.11	37	A619+	28.16
18	PA329	18.25	3	A661	28.33
45	AY499	18.27	59	CH592-46	28.48
3	A661	19.04	88	MO40	28.70
46	AY562	19.27	46	AY562	29.42
106	H100	20.04	50	NYRW3	31.73
81	B75	20.10	35	MS74	32.34
83	B77	20.14	106	H100	32.77
14	ND376	20.46	91	N139	32.82
25	CG11	20.72	98	PA872	33.64
35	MS74	20.77	97	PA871	34.16
17	PA326	20.90	56	CH581-13	35.09
103	H84	21.33	105	H98	35.21
19	PA373	21.56	31	CG17	35.42
2	CO109+	21.72	2	CO109+	35.46
1	CN105+	21.78	41	A635	35.76
67	MS200	21.80	85	B84	35.93
85	B84	22.15	96	PA762	35.96
49	NYD410	22.27	87	MO20W	35.99
75	CH753-4	22.32	1	CN105+	36.25
65	MS75	22.72	95	PA91	36.63
29	CG15	22.94	29	CG15	37.25
53	PA405	23.49	89	MO42	37.37
34	MS72	24.37	53	PA405	38.33
101	FR21	24.87	99	FR16	38.55
100	FR20	25.42	58	CH591-36	38.77
26	CG12	26.72	82	B76	38.85
78	MO17+	27.47	26	CG12	39.35
12	ND300	27.51	77	B73+	39.48
10	ND245	28.76	33	CL1	39.51
44	MO42	29.68	4	A665	39.56
70	W64A+	29.72	67	MS200	39.72
21	CK52	29.78	40	A634	40.02
31	CG17	29.91	94	OH514	40.62
42	A659	30.32	101	FR21	40.81
84	B79	30.39	92	N152	41.59
37	A619+	32.20	103	H84	42.07
43	A670	32.42	83	B77	43.27
38	A632+	32.89	38	A632+	43.51
104	H93	32.93	44	MO42	43.61
93	OH509A	33.15	68	H95	44.24
82	B76	33.28	100	FR20	44.66
28	CG14	33.29	32	CG18	45.58
98	PA872	33.29	75	CH753-4	46.24
77	B73+	33.32	20	PA374	46.28

Table 11. (Continued)

Inbred Line	Code	Incorporation depth 7.5 cm	Inbred Line	Code	Incorporation depth 15.0 cm
32	CG18	33.56	63	B87	46.48
64	MS71	33.89	65	MS75	46.98
41	A635	34.41	30	CG16	47.29
63	B87	34.48	104	H93	48.91
72	W552C	34.93	28	CG14	50.25
62	CH663-8	35.28	39	B85	50.41
66	MS76	35.79	79	N28HT+	50.81
105	H98	36.26	84	B79	50.88
30	CG16	38.77	93	CH509A	51.02
40	A634	38.97	81	B75	51.50
33	CL1	39.25	78	MO17+	53.53
102	H60	40.88	73	W562	53.91
4	A665	41.19	62	CH663-8	54.47
20	PA374	41.62	66	MS76	54.83
6	A671	42.59	102	H60	55.02
39	B85	47.91	72	W552C	55.07
79	N28HT+	51.94	64	MS71	56.02
73	W562	52.32	70	W64A+	56.16
71	W548	58.13	71	W548	58.52
Main effect					
$(\bar{X})$		22.39			32.04

^a Value 0 equals the lowest ranking; the higher the value, the better the inbred line performed.

^b Line 108, code H103, did not germinate, therefore it could not be ranked.

^c Code is from the 1982 IRMIE trial.

^d + represents a check entry, an established line used for maturity placement.

Considering both incorporation depths, the 10 most trifluralin tolerant inbreds in 1982 were: CK52, N152, A670, H93, MS76, B84, H84, OH509A, ND300, and CH581-13. In 1983, the 10 most tolerant inbreds were: W548, W562, N28HT, H60, B85, CH663-8, MS71, CG16, A665, and MS76. The 10 least trifluralin tolerant inbreds in 1982 were: PA373, PA374, A666, PA329, W117HT, ND408, ND474, PA872, CG15, and MS74. In 1983, the 10 least tolerant inbreds were: CK64, H102, ND474, B68, W570, NYRW20, ND408, NY378, CK69, and ND240.

Hybrid corn trifluralin tolerance index values also show a range, although not as large as for the inbreds (Table 12). The relative rank of a hybrid varied with 7.5 to 15 cm incorporation depth and with year.

DISCUSSION

Environmental factors can modify the response of a corn hybrid to trifluralin, as described in Chapter 2 of this thesis. The growing season in East Lansing, Michigan in 1982 was the third coolest on record, while the 1983 season was the third warmest according to the U.S. Weather Bureau. The difference in environment between the two years complicates data interpretation. There was variability in tolerance of individual inbreds and hybrids from 1982 to 1983, but several important conclusions are evident.

The corn lines tested displayed a wide range of tolerance to 0.56 kg/ha trifluralin. The hybrids showed from 5 to 30 percent visual injury, with an average of 16 percent. The inbreds ranged from 10 to 90 percent visual injury (data not presented), with an average of 39

Table 12. Ranking of tolerance index values of Pioneer corn hybrids that were treated with 0.56 kg/ha trifluralin at two incorporation depths in 1982 and 1983 field studies.^a

1982			
Pioneer hybrid	Incorporation depth 7.5 cm	Pioneer hybrid	Incorporation depth 15 cm
3320	37.81	3320	69.33
3572	52.20	3382	75.97
3382	59.01	3572	79.64
3747	61.78	3747	80.43
3541	80.95	3541	92.73
Main effect			
($\bar{X}$)	58.35		79.62
1983			
3382	55.51	3541	57.29
3320	59.78	3382	57.44
3572	62.52	3572	59.26
3541	68.66	3747	63.86
3747	78.81	3320	67.27
Main effect			
($\bar{X}$)	65.06		61.02

^a Value 0 equals lowest ranking; the higher the value, the better the hybrid performed.

percent. This data agrees with Davis et al. (5), who found 0 to 70 percent injury in 52 corn lines. The visual injury decreased as the season progressed, indicating recovery from the trifluralin injury. Injury tended to persist longer with deeper incorporation, as the roots could not escape the herbicide as rapidly. Trifluralin also persists longer at deeper incorporation depths (16, 20).

A small degree of injury was noted in the controls, which may be due to sensitivity of some inbreds and hybrids to the alachlor and simazine used as weed control agents (1, 7, 15). This injury should only be additive, as was found for alachlor in Chapter 2 and for other herbicides applied with trifluralin as reported in the literature (11, 14).

The early maturity inbreds tended to show more injury and a greater stand reduction than other maturity groups. This finding suggests that these inbreds may be inherently more sensitive to trifluralin as a group or that they stop root growth sooner and do not escape trifluralin as readily as other maturity groups.

Differences in the two mechanisms of tolerance can be seen when comparing the response to the two depths of trifluralin incorporation. Trifluralin incorporation to 7.5 cm reduced plant stand more than did 15 cm incorporation in the inbreds both years and the hybrids in 1982. However, the 15 cm incorporation treatment reduced shoot height as a percent of control more than the 7.5 cm incorporation treatment in the hybrids both years. The inbreds showed this tendency also, but due to a large standard deviation, the effects were not significant. The 15 cm trifluralin treatment also increased stunting in the inbreds in 1982. In 1983, many of the

plants that would have been stunted died due to environmental conditions, as reflected in the lower 1983 percent stand.

Individual corn inbreds and hybrids responded differently to the trifluralin at the two incorporation depths, suggesting that two mechanisms are involved in tolerance. These differences can be seen most clearly in the tolerance index values. It is an injury rating method that is less subjective than a visual injury rating. A high tolerance index value for a corn inbred or hybrid to the 7.5 cm trifluralin incorporation depth would suggest tolerance due to rapid downward root growth, while a high tolerance index value to the 15 cm trifluralin incorporation depth would suggest a high physiological tolerance. Inbreds and hybrids low in both were very sensitive to trifluralin.

While there were differences between incorporation depths with the tolerance index there were also differences between years. Based on results presented in Chapter 2, the differences between years were probably due to the differences in temperature between the 1982 and 1983 growing seasons. Hybrid corn tolerance to trifluralin was shown in Chapter 2 to increase or decrease as growing temperatures changed. Inbred corn lines appeared to respond in the same manner.

A range of corn tolerance to 0.56 kg/ha trifluralin was found in 108 inbreds and 5 hybrids. Individual inbreds and hybrids responded differently to the trifluralin incorporation depths of 7.5 or 15 cm. These responses suggest two separate mechanisms for trifluralin tolerance in corn.

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CHAPTER 4

SUMMARY AND CONCLUSIONS

Trifluralin¹ carry-over injury to corn (Zea mays L.) is becoming a more common problem. Conservation tillage methods appear to increase the probability of carry-over injury. The occurrence of injury has been sporadic and unpredictable.

The first study evaluated conditions under which trifluralin injury to corn was most likely to occur. In addition, a range of corn hybrids were tested to determine if genetic variability exists for trifluralin tolerance.

Experiments were conducted in controlled environment chambers and greenhouses to test conditions that could modify trifluralin tolerance. Several corn hybrids were found to be more sensitive to trifluralin at 15 C than at 25 C. Soil moisture differences were not as strong a modifier of trifluralin tolerance as temperature, but did interact with certain hybrids to alter their response to trifluralin. The addition of phosphorus and alachlor [2-chloro-2',6'-diethyl-N-(methoxymethyl)acetanilide] did not alter corn tolerance to trifluralin. Significant differences were found in genetic tolerance of corn to trifluralin within a group of 13 hybrids. The trifluralin tolerance of specific hybrids changed when they were exposed to different environmental conditions.

¹ a,a,a,-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine (TREFLAN)

Differences in trifluralin tolerance exhibited by particular hybrids from field reports and from the experiments above suggested two mechanisms of tolerance. The container experiments tested for physiological tolerance, since the roots could not escape the trifluralin residues. In the field, rapid downward root growth through a trifluralin layer to non-treated soil below could also provide morphological tolerance. A second study was conducted to test a larger range of corn genetic material for trifluralin tolerance and to attempt to determine if there are two mechanisms contributing to trifluralin tolerance in corn.

Field experiments were conducted in 1982 and 1983 with 108 corn inbred lines and 5 hybrids. Trifluralin was incorporated to 7.5 or 15 cm depths. Hybrids showed from 5 to 30 percent visual injury in response to the trifluralin, while the less vigorous inbred lines showed from 10 to 90 percent visual injury. Early maturing inbreds were found to be injured more than later maturing lines. Shallow trifluralin incorporation reduced stand, while deep incorporation reduced shoot height and increased stunting. Individual inbred lines and hybrids also responded differently to the two incorporation depths. Some inbred lines and hybrids displayed tolerance suggesting rapid root growth while others displayed tolerance suggesting high physiological tolerance. Environmental differences between the 1982 and 1983 growing seasons also modified individual inbred line and hybrid response to trifluralin.

In conclusion, the research indicated that many factors interact to influence the expression of corn tolerance to trifluralin carry-over residues. Such factors as soil temperature and moisture,

trifluralin residue amount and depth of incorporation, corn maturity, and the amount of genetic tolerance due to physiological and/or morphological traits can alter the manner in which corn responds to trifluralin. With so many factors involved, accurate predictions of trifluralin carry-over on a field by field basis would be very difficult. However, the inbred lines identified as being very sensitive to trifluralin can be avoided for use in producing hybrids. The best solution to the problem of trifluralin carry-over would be to utilize the genetic variability identified in these studies to breed for trifluralin tolerance in corn.

Inbred lines have been identified that have good tolerance due to one or both mechanisms. By using these inbred lines to produce hybrids, the potential exists to produce a hybrid that will tolerate trifluralin carry-over residues with no injury. This advance should be readily achievable, since several hybrids tested showed little injury to 0.56 kg/ha trifluralin. In addition, the lines with rapid downward root growth may produce hybrids with more stress tolerance, due to early deep rooting. If corn trifluralin tolerance could be advanced to a level where trifluralin could be safely used as a weed control agent, the cost of corn production would decrease and problem grass weeds could be controlled cheaply and effectively.

APPENDIX

Table A1. The interaction of trifluralin, soil moisture level, and temperature on four Pioneer corn hybrids.^a

Effects to be compared	Trifluralin (kg/ha)	Pioneer hybrid	Soil moisture capacity	Temperature (C)	Shoot		Root	
					length (cm)	fresh wt (g)	dry wt (g)	fresh wt (g)
Interaction	0	3747	48	15	11.9 n-q	0.51 q-t	0.06 lm	2.09 k-p
				25	37.3 d-h	2.45 ef	0.41 a-e	5.06 bod
			100	15	21.9 kl	1.26 k-n	0.18 h-l	2.81 h-l
				25	45.5 ab	3.62 a	0.54 a	5.59 b
	3320		48	15	12.1 n-q	0.55 q-t	0.07 lm	2.46 i-m
				25	35.7 e-i	2.21 efg	0.40 a-f	6.59 a
			100	15	21.2 kl	1.25 k-n	0.18 h-m	3.02 g-k
				25	43.2 bc	3.08 bc	0.47 abc	5.62 b
	3572		48	15	9.9 o-r	0.42 rst	0.06 lm	1.80 l-t
				25	36.7 d-h	2.03 fgh	0.36 a-i	4.73 b-e
			100	15	20.8 kl	1.14 k-o	0.16 i-m	3.04 g-k
				25	49.3 a	3.47 ab	0.47 abc	5.43 bc
	3541		48	15	10.6 opq	0.49 q-t	0.05 lm	2.06 k-q
				25	38.1 def	2.26 efg	0.39 a-g	5.32 bc
			100	15	24.5 k	1.39 kl	0.20 f-m	3.32 g-j
				25	48.3 a	3.45 ab	0.51 ab	5.51 b
	0.22	3747	48	15	10.7 opq	0.45 q-t	0.09 lm	1.36 m-u
				25	33.6 f-j	1.86 g-k	0.32 b-k	3.89 e-h
			100	15	21.8 kl	1.19 k-o	0.18 h-m	1.87 l-s
				25	43.9 bc	2.96 cd	0.46 abc	3.41 f-i
	3320		48	15	8.3 pqr	0.33 st	0.06 lm	1.12 o-u
				25	32.9 hij	1.62 h-k	0.31 b-k	4.63 b-e
			100	15	21.8 kl	1.17 k-o	0.19 g-m	1.92 k-r
				25	41.3 bod	2.55 de	0.45 a-d	4.41 c-f

Table A1. (Continued)

Effects to be compared	Trifluralin (kg/ha)	Pioneer Soil hybrid moisture	Temperature (C)	Length (cm)	Shoot		Root	
					fresh wt	dry wt	fresh wt	dry wt
		(% field capacity)			(g)	(g)	(g)	(g)
Interaction	0.22	3572	48	7.5 gr	0.31 st	0.04 lm	0.71 tu	0.26 e
				34.0 f-j	1.47 jk1	0.23 e-m	2.37 i-n	0.53 b-e
		100	15	18.8 lm	1.01 l-p	0.16 i-m	1.78 l-u	0.31 e
			25	39.5 cde	2.05 fgh	0.30 c-k	3.39 f-i	0.42 cde
		3541	48	10.6 opq	0.47 q-t	0.08 lm	1.24 n-u	0.32 e
			25	33.2 g-j	1.56 ijk	0.26 d-l	3.48 f-i	0.57 b-e
		100	15	16.4 mn	0.85 m-r	0.15 j-m	1.35 m-u	0.28 e
			25	43.7 bc	2.59 de	0.37 a-h	4.04 d-g	0.48 cde
	0.45	3747	48	10.1 o-r	0.39 rst	0.06 lm	1.02 p-u	0.24 e
			25	32.6 hij	1.44 jk1	0.22 e-m	1.95 k-r	0.40 cde
		100	15	15.3 mn	0.76 o-s	0.13 j-m	1.25 n-u	0.24 e
			25	39.7 cde	2.51 e	0.39 a-f	2.24 j-o	0.39 cde
		3320	48	7.8 gr	0.29 st	0.06 lm	0.83 r-u	0.34 de
			15	29.9 j	1.32 klm	0.26 d-l	2.26 j-o	0.66 b-e
		100	25	13.8 no	0.65 p-t	0.12 klm	1.12 o-u	0.33 de
			25	37.8 d-g	1.96 ghi	0.33 b-j	2.42 i-m	0.49 cde
		3572	48	5.7 r	0.22 t	0.03 m	0.64 u	0.25 e
			25	23.8 k	0.90 m-q	0.15 j-m	1.40 m-u	0.35 de
		100	15	12.8 nop	0.48 q-t	0.09 lm	0.78 stu	0.20 e
			25	36.7 d-h	1.52 ijk	0.23 e-m	1.67 l-u	0.27 e
		3541	48	9.3 o-r	0.40 rst	0.07 lm	0.93 q-u	0.25 e
			25	31.7 ij	1.42 jk1	0.22 e-m	2.16 k-p	0.45 cde
		100	15	16.2 mn	0.83 n-r	0.14 j-m	1.15 o-u	0.23 e
			25	43.7 bc	2.67 cde	0.42 a-e	2.58 i-l	0.40 cde

a Means within a column with a common letter are not significantly different at the 5% level by the Duncan's multiple range test.

Table A2. The interaction of trifluralin, soil moisture level, and temperature on three parameters of four Pioneer corn hybrids as a percent of control.^a

Effects to be compared	Trifluralin (kg/ha)	Pioneer hybrid	Soil moisture (% field capacity)	Temperature (C)	Shoot		Root	
					fresh wt	dry wt	dry wt	dry wt
					-----(% of control)-----			
Interaction	0.22	3747	48	15	87.9 abc	99.9 ab	107.7 a	
				25	75.7 a-f	74.6 b-h	101.1 ab	
			100	15	95.7 a	91.0 a-d	74.8 d-h	
				25	85.6 a-d	85.8 a-e	68.4 f-j	
		3320	48	15	59.0 e-h	80.9 a-g	77.1 c-h	
				25	73.2 a-f	75.0 b-h	69.3 f-j	
			100	15	83.4 a-d	84.2 a-f	83.9 b-f	
				25	79.6 a-e	95.8 abc	94.8 a-e	
		3572	48	15	74.4 a-f	81.3 a-g	82.8 b-g	
				25	71.9 b-g	60.4 e-j	80.8 b-g	
	0.45	3541	100	15	89.1 ab	92.4 a-d	71.1 e-i	
				25	62.7 d-h	56.2 g-k	70.2 f-i	
			48	15	96.3 a	103.2 a	97.4 a-d	
				25	69.2 b-g	60.0 e-j	60.3 f-k	
			100	15	69.4 b-g	79.5 a-g	80.7 b-g	
				25	74.9 a-f	70.3 c-i	84.1 b-f	
		3747	48	15	77.8 a-e	92.4 a-d	84.1 b-f	
				25	58.8 e-h	46.3 ijk	44.3 k	
			100	15	62.7 d-h	81.3 a-g	66.2 f-k	
				25	70.1 b-g	72.9 c-h	58.8 g-k	
			3320	48	15	53.3 fgh	82.7 a-g	78.3 b-g
					25	59.3 e-h	58.0 f-j	49.9 ijk
		3572	100	15	48.6 gh	56.0 g-k	76.4 c-h	
				25	64.8 c-h	67.8 d-i	74.8 d-h	
			48	15	59.1 e-h	51.6 h-k	82.6 b-g	
				25	44.0 h	31.6 k	50.8 ijk	
			100	15	43.9 h	52.5 h-k	47.8 ijk	
				25	43.7 h	39.6 jk	46.1 jk	

Table A2. (Continued)

Effects to be compared	Trifluralin (kg/ha)	Pioneer hybrid	Soil moisture (% field capacity)	Temperature (C)	Shoot		Root	
					fresh wt	dry wt	fresh wt	dry wt
					-----(% of control)-----			
Interaction	0.45	3541	48	15	82.1 a-e	104.6 a	100.0 abc	
				25	62.9 d-h	49.4 h-k	54.2 h-k	
			100	15	71.1 b-g	68.5 d-i	61.9 f-k	
				25	77.5 a-e	82.3 a-g	77.1 c-h	
Interaction of hybrid by soil moisture		3747	48		75.0 a	78.3 a	84.3 a	
			100		78.6 a	82.7 a	67.1 de	
		3320	48		61.2 b	74.1 a	68.7 cde	
			100		69.1 ab	75.9 a	82.5 ab	
		3572	48		62.3 b	56.2 b	74.2 bcd	
			100		59.8 b	60.2 b	58.8 e	
Interaction of hybrid by temperature		3541	48		77.6 a	79.3 a	78.0 abc	
			100		73.2 a	75.1 a	75.9 a-d	
		3747		15	81.0 a	91.2 a	83.2 a	
				25	72.6 abc	69.9 bc	68.2 cd	
Main effect of trifluralin	0.22 0.45	3320		15	61.0 de	75.9 b	78.9 ab	
				25	69.2 cd	74.2 bc	72.2 bc	
		3572		15	66.6 cde	69.4 bc	71.0 bcd	
				25	55.6 e	47.0 d	62.0 d	
		3541		15	79.7 ab	88.9 a	85.0 a	
				25	71.1 bcd	65.5 c	68.9 cd	
					78.0 a	80.7 a	81.5 a	
						61.2 b	64.8 b	65.8 b

Table A2. (Continued)

Effects to be compared	Trifluralin (kg/ha)	Pioneer hybrid	Soil moisture (% field capacity)	Temperature (C)	Shoot		Root	
					fresh wt	dry wt	fresh wt	dry wt
					-----(% of control)-----			
Main effect of hybrid		3747			76.8 a	80.5 a	75.7 a	
		3320			65.1 b	75.0 a	75.6 a	
		3572			61.1 b	58.2 b	66.5 b	
		3541			75.4 a	77.2 a	76.9 a	
Main effect of soil moisture			48		69.0 a	72.0 a	76.3 a	
			100		70.2 a	73.5 a	71.1 b	
Main effect of temperature				15	72.1 a	81.4 a	79.5 a	
				25	67.1 b	64.1 b	67.8 b	

a Means within a column within an effects group with a common letter are not significantly different at the 5% level by the Duncan's multiple range test.

Effects of Trifluralin on Phosphorus Uptake and Hybridity in *Brassica napus* L.

Effects to be compared	Trifluralin (kg/ha)	Phosphorus as P ₂ O ₅ (kg/ha)	Hybrid ^b	Shoot		Root			
				length (cm)	fresh wt (g)	length (cm)	fresh wt (g)		
Interaction	0	0	3901	26.5 cd	2.27 e-i	0.63 b-l	51.5 d-h	7.99 d-h	0.79 d-i
			3184	26.6 cd	2.25 e-i	0.61 b-m	50.4 e-h	8.43 c-g	0.80 c-i
			SPX 49	26.6 cd	1.97 g-k	0.53 e-p	42.8 i	6.96 g-j	0.66 h-p
			3732	26.1 cde	2.27 e-i	0.63 b-l	51.0 d-h	7.78 e-h	0.73 e-m
			3747	27.8 bc	2.34 d-i	0.65 a-j	48.1 f-i	7.38 f-i	0.72 e-m
			3186	24.8 d-g	2.06 g-j	0.58 c-n	53.8 c-f	8.65 c-g	0.77 d-k
			3541	28.3 bc	2.50 b-g	0.64 a-k	59.6 b	9.68 a-e	0.85 a-f
			3535	31.4 a	2.97 b	0.77 abc	50.5 e-h	9.94 a-e	0.90 a-e
			3320	26.3 cde	2.25 e-i	0.65 a-i	53.5 c-f	10.21 a-d	0.99 ab
			3572	25.9 c-f	1.99 g-k	0.51 e-q	51.5 d-h	8.72 c-g	0.84 a-g
			3382	25.9 c-f	2.23 e-i	0.59 b-n	49.8 e-h	10.03 a-d	0.87 a-f
			x-6362	28.2 bc	2.31 d-i	0.66 a-h	65.3 a	8.65 c-g	0.78 d-j
			x-7382	23.4 f-i	1.82 i-l	0.51 e-q	56.7 bcd	8.76 b-g	0.80 c-i
			3901	27.7 bc	2.85 bcd	0.79 ab	60.3 ab	11.06 a	0.97 abc
			3184	29.9 ab	2.90 bc	0.74 a-d	49.9 e-h	10.95 ab	1.01 a
			SPX 49	26.5 cd	2.36 d-i	0.59 b-n	42.6 i	8.35 c-g	0.70 f-n
			3732	27.0 cd	2.83 bcd	0.77 abc	46.6 hi	9.69 a-e	0.89 a-e
			3747	26.8 cd	2.52 b-g	0.69 a-e	50.0 e-h	9.43 a-f	0.93 a-d
			3186	23.4 f-i	2.24 e-i	0.59 c-n	53.7 c-f	10.45 abc	0.86 a-f
			3541	28.6 bc	2.73 b-e	0.68 a-f	53.4 c-f	9.95 a-e	0.82 b-h
3535	32.1 a	3.43 a	0.83 a	53.1 c-g	9.91 a-e	0.86 a-f			
3320	27.3 bcd	2.40 c-h	0.67 a-g	58.3 bc	11.15 a	0.93 a-d			
3572	26.7 cd	2.63 b-f	0.63 b-l	52.9 c-g	9.80 a-e	0.85 a-f			
3382	26.1 cde	2.51 b-g	0.66 a-h	47.2 ghi	10.94 ab	0.94 a-d			
x-6362	27.1 cd	2.26 e-i	0.56 d-o	55.3 b-e	9.05 a-g	0.73 e-l			
x-7382	22.9 g-k	1.89 h-k	0.47 h-q	51.8 d-h	8.59 c-g	0.66 g-p			

Table A3. (Continued)

Effects to be compared	Trifluralin as P ₂ O ₅	Phosphorus Hybrid	Shoot		Root	
			length	fresh wt	length	fresh wt
	(kg/ha)	(kg/ha)	(cm)	(g)	(cm)	(g)
Interaction	0.45	0				
		3901	20.0 l-r	1.44 k-o	6.4 j	4.52 klm
		3184	19.5 m-s	1.21 mno	6.7 j	4.37 klm
		SPX 49	17.1 s	1.08 no	7.1 j	4.11 klm
		3732	20.8 i-o	1.22 mno	5.8 j	3.97 klm
		3747	22.0 h-m	1.69 j-m	7.2 j	4.68 klm
		3186	17.7 qrs	1.23 mno	7.1 j	4.50 klm
		3541	20.8 i-o	1.47 ko	8.0 j	4.72 klm
		3535	21.5 h-n	1.52 j-o	8.6 j	3.99 klm
		3320	21.3 h-n	1.65 j-n	9.0 j	5.31 jkl
		3572	18.4 o-s	1.18 mno	6.9 j	4.12 klm
		3382	17.0 s	1.11 no	6.7 j	3.91 klm
		x-6362	17.3 r-s	1.08 o	5.6 j	3.04 m
		x-7382	19.1 n-s	1.45 k-o	7.6 j	4.36 klm
	112	3901	21.5 h-n	1.53 j-o	6.4 j	4.31 klm
		3184	20.6 j-p	1.29 l-o	5.5 j	3.87 klm
		SPX 49	20.3 k-q	1.60 j-o	7.7 j	4.76 klm
		3732	22.6 g-l	1.55 j-o	6.0 j	4.37 klm
		3747	23.8 e-h	2.07 f-j	7.5 j	5.12 j-m
		3186	18.4 o-s	1.52 j-o	7.6 j	5.41 i-l
		3541	21.5 h-n	1.52 j-o	8.6 j	4.70 klm
		3535	22.2 g-m	1.58 j-o	10.5 j	4.84 klm
		3320	23.3 g-j	1.86 h-k	8.5 j	6.09 h-k
		3572	18.0 p-s	1.08 o	8.1 j	3.56 lm
		3382	17.4 rs	1.14 mno	6.8 j	3.79 lm
		x-6362	17.9 qrs	1.18 mno	5.9 j	3.47 lm
		x-7382	18.2 o-s	1.47 k-o	7.8 j	5.01 j-m
						0.63 i-p
						0.57 l-s
						0.56 l-s
						0.56 l-s
						0.59 l-r
						0.60 k-q
						0.53 n-s
						0.53 n-s
						0.69 f-o
						0.53 n-s
						0.48 p-s
						0.40 s
						0.51 o-s
						0.56 l-s
						0.52 o-s
						0.55 l-s
						0.55 m-s
						0.66 h-p
						0.61 j-q
						0.51 o-s
						0.57 l-s
						0.81 b-h
						0.40 s
						0.45 qrs
						0.42 rs
						0.57 l-s

a Means within a column with a common letter are not significantly different at the 5% level by the Duncan's multiple range test.

b With the exception of SPX 49, a Migro hybrid, all are Pioneer hybrids.

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