To the Graduate Council:

I am submitting herewith a dissertation written by Mary Angela Harrison entitled "Effect of Environment on Plant Response to DPX-PE350 [sodium 2-chloro-6-(4,5-dimethoxy-pyrimidin-2-ylthio)benzoate]." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant and Soil Science.

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EFFECT OF ENVIRONMENT ON PLANT RESPONSE TO DPX-PE350 [SODIUM 2-CHLORO-6-(4,5-DIMETHOXY-PYRIMIDIN-2-YLTHIO)BENZOATE]

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Mary Angela Harrison

August, 1993

DEDICATION

In memory of James Porter Thompson (1904-1991)

and James Bernard Elliott (1893-1975).

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ABSTRACT

Environmental conditions at the time of spraying can affect the activity of foliar-applied herbicides. Evaluation of environmental effect on experimental herbicides is one important area of research. DPX-PE350 is a potential cotton herbicide for postemergence broadleaf weed control.

Greenhouse and growth chamber studies were conducted to determine the DPX-PE350 rate causing 50% growth reduction (GR_{50}) in cotton (*Gossypium hirsutum* L.), velvetleaf (*Abutilon theophrasti*) and sicklepod (*Cassia obtusifolia*), the effect of time until rainfall on DPX-PE350 activity on velvetleaf, and the effect of soil moisture on root uptake from foliar-applied DPX-PE350. Additional experiments were conducted with formulated and radiolabeled DPX-PE350 to determine the effect of soil moisture and ambient temperature on DPX-PE350 activity on cotton and velvetleaf.

In whole-plant studies, data were collected 2 to 4 wk after treatment (WAT). Foliar chlorosis and stunting were visually evaluated, and plant heights and/or fresh weights were recorded. In ^{14}C experiments, absorption and translocation were measured 6, 24, and 72 h after treatment with ^{14}C-DPX-PE350. ^{14}C was detected with liquid scintillation spectroscopy.

Velvetleaf GR_{50} at 2 WAT occurred with DPX-PE350 at 70 g

ai ha^{-1}. A GR_{50} for sicklepod and cotton was not observed at the examined rates because of high tolerance to DPX-PE350.

Velvetleaf injury was greatest when 5 h lapsed before a 5 mm simulated rainfall event. Injury was observed when 0.08 h lapsed before the rainfall event, possibly because DPX-PE350 moved from foliage into the soil where uptake by plant roots could occur.

DPX-PE350 applied to velvetleaf foliage accounted for most injury, although root uptake contributed to herbicide activity at -0.03 MPa soil moisture. Velvetleaf injury was greatest when DPX-PE350 was applied to plants growing at soil moistures of -0.03 MPa compared to -1 MPa, and when DPX-PE350 was applied simultaneously to foliage and soil.

DPX-PE350 injury to cotton was <20% 2 WAT on plants grown at 25/23, 30/28, or 35/33 C, at soil moistures of -0.03, -0.5, or -1 MPa. DPX-PE350 injured velvetleaf less at lower soil moistures.

Cotton and velvetleaf absorbed more ^{14}C-DPX-PE350 at 30/28 or 35/33 C than at 25/23 C. Cotton absorbed more herbicide than velvetleaf at all temperatures and soil moistures but translocated <3% of absorbed material. At warmer temperatures, velvetleaf absorbed and translocated less ^{14}C when soil was dry (-1.0 MPa) than when plants were watered to field capacity (-0.03 MPa). This decrease in absorption and translocation may partially explain reduced DPX-PE350 activity on velvetleaf growing in dry soil.

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PART I

INTRODUCTION

POSTEMERGENCE WEED CONTROL IN COTTON

Herbicides control weeds which compete with cotton for light, nutrients, and moisture. Herbicides are used more intensively in cotton than any other major crop in the United States (16). Cotton is a warm season perennial planted in early spring when soil temperatures are 13 to 18 C (16). Cotton competes poorly with weeds which emerge earlier and grow faster at cooler temperatures. Herbicides are applied preplant incorporated, preemergence, postemergence, and post-directed.

Postemergence herbicides control weeds that escape soil-applied herbicides. Preplant or preemergence herbicides may only suppress certain weeds, or fail to control high densities of susceptible weeds. The continuous use of specific herbicide chemistries has changed the composition and herbicide tolerance of weed populations (13). In these situations, postemergence herbicide regimes can be adapted to control special weed problems, and they are essential to the successful practice of conservation tillage and no-tillage, since cultivation to control weed escapes is not usually performed.

Several postemergence herbicides will selectively control grasses in cotton. Yet, cotton is the only major agronomic crop with no registered selective over-the-top broadleaf herbicide. Instead, herbicides must be post-directed between cotton rows or at the base of cotton plants to prevent cotton injury. Equipment failure or a lack of height differential between cotton and weeds can cause severe injury and subsequent yield reduction. There is much interest in developing herbicides with cotton selectivity and efficacy on troublesome broadleaf weeds.

ABSORPTION AND TRANSLOCATION OF FOLIAR HERBICIDES

Postemergence herbicides must reach the site(s) of action in sufficient quantity to cause herbicidal effects. Absorption and translocation affect the amount of herbicide arriving at active site(s). The mechanisms of absorption and translocation have been partially elucidated for some herbicides. Yet, this research is complicated by morphological and physiological differences between and within plant species.

Absorption consists of herbicide movement through the cuticle into the cell wall or cytoplasm of epidermal cells (6). Translocation, involving apoplastic or symplastic movement to the site(s) of action, may or may not occur (20).

The cuticle is a noncellular, lipoidal membrane covering foliar structures including trichomes, guard cells, and the cells lining the substomatal chamber (19). The cuticle is composed of epicuticular wax and a cutin matrix embedded with cuticular waxes (20). Composition may depend on the species and vary with plant age and environmental conditions (6). Components of cuticles of different species have been extensively reviewed by Baker (2) and Crafts and Foy (6). The cuticle prevents excessive water loss and protects the plant from radiation and frost damage (15). It also acts as a barrier to foliar-applied chemicals.

Herbicides move by diffusion through the surface cuticle, while lesser amounts diffuse as a vapor through stomata or move as a liquid through open stomata (6, 20). Cells at the base of trichomes and hydathodes or lenticels may be entry sites for limited amounts of herbicide (6, 15, 11).

Price (21) substituted the Stokes-Einstein equation in Fick's first law of diffusion to describe factors affecting herbicide penetration through the cuticle:

$$J = \frac{k^B \times T \times K}{6\pi r \times \eta \times \Delta x \times l}(Co - Ci).$$

where: J = flux, k^B = Boltzman constant, T = temperature, K = (log) partition coefficient, r = radius of solute molecule, n = viscosity of solvent, Δ X x l = thickness of the cuticle, C_o = herbicide concentration outside the cuticle, and C_i = herbicide concentration inside the cuticle. Herbicide absorption generally increases as temperature increases, and temperatures close to 30 C may have the greatest affect on absorption (21). Solute pH (5) and herbicide octanol:water partition coefficient (K_{ow}) (4) have been implicated in absorption rates. Herbicides of medium lipophilicity (K_{ow} = 1 to 3) are absorbed more rapidly than more polar or more lipophilic compounds, and acids are absorbed more slowly than nonionized compounds presumably due to slow penetration of anions (4). The K_{ow} of acid herbicides may be pH dependent (21). Cuticle thickness (xl) may depend on the age, species, or environment, and involves a tortuosity factor (l) to describe movement through a nonhomogeneous layer.

Separate routes of entry are proposed for polar and nonpolar herbicides (15). Nonpolar herbicide diffuse through the lipid components of the cuticle while polar herbicides diffuse through the more hydrated cutin matrix (20). Rapid foliar uptake of some polar compounds supports the theory of an aqueous continuum across the cuticle.

Surfactants may increase herbicide penetration. This may be due to increased surface coverage and improved deposition (6) or to disruption or solubilization of cuticular waxes (5).

Mechanisms of absorption into cells are not clearly understood. Atrazine (23) and glyphosate (8) appear to diffuse passively. Certain weak acid herbicides move by diffusion and it has been postulated that a plasmalemma carrier protein may be involved (11). An "ion trap effect" has been proposed for other weak acid herbicides (17, 26) in which protonated acids cross the plasmalemma into the cytoplasm, become dissociated, and remain inside the cytoplasm as anions.

Once inside leaf tissues, systemic herbicides translocate by apoplastic (xylem vessels or tracheids), symplastic (sieve tubes of phloem) routes, or by a combination of the two (7). Mechanism(s) of translocation are not clearly understood for many herbicides, but it is proposed that weak acid herbicides are most readily translocated in the phloem and dissociate due to the high phloem pH (7) in a mechanism similar to the ion trap theory proposed for cellular absorption of certain weak acid herbicides (26).

ENVIRONMENTAL EFFECT ON ABSORPTION AND TRANSLOCATION OF FOLIAR HERBICIDES

Environmental factors affect plant development and may contribute to variability in foliar herbicide activity. The influence of each factor on absorption and translocation has not been clearly determined because species respond differently to environmental stresses and to herbicides.

Soil moisture stress (deficit) or high light intensity increases both the quantity and composition of surface waxes in a variety of plants (1, 3, 10). Skoss (24) noted that high temperatures enhance wax formation on some plants, but the opposite has been reported for other species (1). It has been postulated that soil moisture stress reduces translocation in the phloem by reducing photosynthate production (source strength) and by reducing growth in new tissues (sink strength) due to lack of adequate moisture (9).

Herbicide absorption increases at higher temperatures for certain herbicides (14). Other herbicides have greater absorption at low temperatures when relative humidity is high (18). Soil moisture deficit causes less absorption (12, 25) and lower translocation (22, 12, 25) of other herbicides.

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PART II

LITERATURE REVIEW

DPX-PE350

DPX-PE350, formerly KIH-8921 [sodium 2-chloro-6-(4,5-dimethoxy-pyrimidin-2-ylthiol)benzoate], originally discovered by Kumiai, a Korean chemical company, is currently being developed by E.I. DuPont de Nemours, and Co., for over-the-top broadleaf weed control in cotton. The compound possesses a unique chemistry and is not a member of any existing herbicide family. Suggested common and trade names are sodium salt of pyrithiobac and "Staple", respectively (2). Proposed use rates are <200 g ai ha^{-1}(8).

Mitchell (8) reported that DPX-PE350 is rapidly absorbed by both foliage and roots of plants. Like the sulfonylureas and imidazolinones, DPX-PE350 acts by inhibiting acetolactate synthase (ALS), an enzyme in the biosynthetic pathway of valine, leucine, and isoleucine (8). Inhibition of corn (*Zea mays* L.) ALS activity by DPX-PE350 was similar to inhibition by the sulfonylurea herbicide, chlorsulfuron (2-chloro-N-[[(4-methoxy-6-methyl-1, 3, 5-triazin-2-yl)amino]carbonyl]-benzenesulfonamide) (4). ALS inhibition causes plants to appear stunted and chlorotic. Death generally occurs slowly (1 to 2 wk) as protein synthesis, cell division and growth are inhibited and metabolic precursors build up causing plant death (8).

Differential metabolism to non-toxic metabolites is the basis of selectivity in sensitive versus tolerant morningglory (*Ipomoea)* species (11). This is the selectivity mechanism of other ALS-inhibiting herbicides (3, 12).

DPX-PE350 EFFICACY AND PHYTOTOXICITY

Cotton is most tolerant when DPX-PE350 is applied postemergence (8). Slight chlorosis and stunting observed in field experiments (6) generally disappears within 10 d (7). No adverse effect has been observed on maturity or lint quality (4, 5, 9). Postemergence DPX-PE350 may be most injurious to one- to two-leaf cotton (9) and may injure four- to eight-leaf cotton treated with 220 g ai ha^{-1} (13).

DPX-PE350 provides effective control of several broadleaf weeds which are troublesome in the Southeast such as various morningglory (*Ipomoea*) species, velvetleaf (*Abutilon theophrasti*), common cocklebur (*Xanthium strumarium*), spurred anoda (*Anoda cristata*), and pigweed (*Amaranthus*) species (2, 8). DPX-PE350 is active on weeds when applied to the soil or foliage, however foliar applications may give more consistent results. DPX-PE350 early postemergence (two- to 3-leaf cotton) applications provided more control (>90%) of pitted (*Ipomoea lacunosa*) and entireleaf morningglory (*Ipomoea hederacea* var. 'integriuscula') (5), prickly sida (*Sida spinosa*), common cocklebur, and redroot pigweed (*Amaranthus retroflexus*) (1) than preemergence. Vidrine et al., (13) reported that twice as much DPX-PE350 was needed to control morningglory preemergence compared to postemergence treatments.

Little is known about the effect of environmental factors on the efficacy or phytotoxicity of DPX-PE350. Sims, et al., (10) partially attributed a decrease in velvetleaf control to environmental conditions present at the time of application. Other researchers[1] have observed greater cotton injury when DPX-PE350 is applied to cotton growing under cool, cloudy, wet conditions.

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[1]Dr. C. S. Williams, and Dr. W. Mitchell, personal communication.

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PART III

EFFECT OF DPX-PE350 RATE, SIMULATED RAINFALL, AND SOIL MOISTURE ON RESPONSE OF COTTON, SICKLEPOD, OR VELVETLEAF TO DPX-PE350

ABSTRACT[1]

Cotton, sicklepod, and velvetleaf response to increasing rates of DPX-PE350, rainfall effect, and soil moisture effect on root uptake from foliar DPX-PE350 was examined under controlled conditions. Velvetleaf growth reduction of 50% (GR_{50}) occurred at 2 wk after treatment (WAT) from 70 g ha^{-1} DPX-PE350. Cotton and sicklepod GR_{50} was >560 g ha^{-1} DPX-PE350. Velvetleaf was injured most when 5 h lapsed before a simulated 5 mm rainfall event. Injury was observed when 0.08 h lapsed before rainfall, possibly because DPX-PE350 moved from foliage into the soil where uptake by plant roots could occur. DPX-PE350 application to foliage accounted for most velvetleaf injury, although soil uptake contributed to herbicide activity at -0.03 MPa soil moisture. DPX-PE350 injury to velvetleaf was greater at soil moistures of -0.03 MPa compared to -1 MPa, and when DPX-PE350 was applied simultaneously to foliage and soil. **Nomenclature:** DPX-PE350, sodium 2-chloro-6-(4,5-dimethoxy-pyrimidin-2-ylthio)benzoate; velvetleaf, *Abutilon*

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[1]To be submitted for publication in *Weed Science*. Authors: M. Angela Harrison, Robert M. Hayes, Thomas C. Mueller. Former Grad. Res. Asst., Prof., and Asst. Prof., respectively, Dept. of Plant and Soil Sci., Univ. of Tennessee, Knoxville, TN 37901. Current address of senior author: 3107 Salem Road, Milan, TN 38358.

theophrasti Medik #[2] ABUTH, sicklepod, *Cassia obtusifolia*; cotton, *Gossypium hirsutum* L 'Deltapine 50'. Additional index words. *Abutilon theophrasti*, *Gossypium hirsutum*, ABUTH, GOSHI, growth chamber, greenhouse, soil moisture, GR_{50}, weed control, herbicide.

INTRODUCTION

DPX-PE350, a postemergence herbicide, is being developed by E.I. DuPont de Nemours and Co. for control of problem weeds such as velvetleaf in cotton, at rates of 70 to 140 g ha^{-1} (8). DPX-PE350 activity on velvetleaf may be adversely affected by environmental conditions in the field (12).

The time of a rainfall event relative to herbicide application (2, 4, 13) and soil moisture (9) affect the efficacy of various foliar-applied herbicides. A premature rainfall may wash herbicide from treated leaves before a lethal dose is absorbed (1, 13). Soil moisture stress may influence leaf cuticular composition and foliar penetration (5, 6) and decreases the activity of both foliar and soil-applied herbicides (7).

Interaction of DPX-PE350 with environmental conditions

[2]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

at the time of application has not been thoroughly investigated. The first objective was to determine DPX-PE350 rates causing 50% growth reduction (GR_{50}) of cotton, sicklepod, and velvetleaf grown in the growth chamber. Next, effect of rainfall was evaluated and the importance of soil moisture and root uptake on activity of over the top DPX-PE350 application was determined.

MATERIALS AND METHODS

General procedures. Plants were grown in separate 10 cm diameter styrofoam pots, perforated for drainage, which contained surface soil of the Etowah silt loam series (fine-loamy, siliceous, thermic typic Paleudults). Seeds of cotton, sicklepod, and velvetleaf were planted and seedlings were thinned to one cotton, three sicklepod, or three velvetleaf plants per pot, 1 to 2 wk after emergence. For soil moisture experiments, velvetleaf plants were thinned to one plant per pot. In the greenhouse, pots were watered daily or as needed with an overhead irrigation system. In the growth chamber, pots were subirrigated initially and then hand watered from the top during experiments. Pots were fertilized[3] from the top 2 to 3 d before herbicide application. DPX-PE350 treatments contained 0.25% (v/v)

[3]Peters Professional All Purpose 20-20-20. Grace-Sierra Horticultural Products Co., 1001 Yosemite Dr., Milpitas, CA.

non-ionic surfactant[4].

Data collected were visual injury and/or fresh weight reduction. Foliar chlorosis and stunting were visually evaluated on a scale of 0 to 100 where 0 was no injury and 100 equaled plant death. Plants were harvested by cutting the plant stem at the soil surface. For purposes of presentation, shoot fresh weights were expressed as a percent of the untreated controls.

GR_{50} experiments. Growth chamber experiments were conducted to determine the rate of DPX-PE350 causing a GR_{50} in cotton, sicklepod (tolerant), and velvetleaf (sensitive). Plants were established as previously described and then grown at conditions of 30/25 C day/night temperature, 60% relative humidity, and 620 uMol m^{-2} s^{-1} light intensity in a 14 h photoperiod.

DPX-PE350 was applied at 0, 11, 35, 70, 140, or 280 g ha^{-1} to velvetleaf and at 0, 70, 140, 280, 420, or 560 g ha^{-1} to cotton and sicklepod. All plants were at the four- to five-leaf stage. Application was made with a CO_2-pressurized backpack sprayer equipped with flat fan[5] nozzles delivering 170 L ha^{-1} at 270 KPa. Plants were harvested

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[4]X-77 (alkylaryl-polyoxyethylene glycols, free fatty acids, and isopropanol). Valent U.S.A. Corp., 1333 North California Blvd., Walnut Creek, CA 94596.

[5]TeeJet 8002 tips. Spraying Systems Co., Wheaton, IL 60187.

after 3 wk and shoot fresh weights were determined. Treatments were replicated four times in the experiment which was conducted twice.

Effect of rainfall. Greenhouse studies were initiated to determine if rainfall after application affected DPX-PE350 activity on velvetleaf. Velvetleaf plants were established as described previously and grown at 35 to 25 C ambient temperature, 60 to 80% relative humidity, and natural sunlight in the greenhouse.

DPX-PE350 was applied at 70 or 140 g ha^{-1} followed by a 5 mm simulated rainfall event at 0.08, 0.25, 0.5, 1, 3, or 5 h. DPX-PE350 was applied to two- to three-leaf plants with a CO_2-pressurized mechanical spray chamber equipped with even-spray nozzles[6] delivering 190 L ha^{-1} at 270 KPa. Pots were transferred from the greenhouse to a nearby building which housed the mechanical spray chamber for application of DPX-PE350. Pots were then returned to the greenhouse for the simulated rainfall which was provided by an overhead sprinkler irrigation system.

Plants were evaluated for visual injury and fresh weight reduction 4 WAT. Treatments were replicated three times in the experiment which was conducted twice.

Soil moisture, root uptake and DPX-PE350 efficacy. A growth chamber study was initiated to measure the effect of soil

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[6]Teejet 8001E tips. Spraying Systems Co., Wheaton, IL 60187.

moisture on DPX-PE350 activity from root uptake of herbicide reaching the soil following foliar application. Velvetleaf plants were grown as described earlier. Growth chamber conditions were 30/28 C day/night temperature, 60% relative humidity, and a 12 h photoperiod (620 uMol m^{-2} s^{-1}).

Treatments were soil moistures of -0.03 or -1.0 MPa in a complete factorial with the following application regimes: a) plant covered, herbicide applied to soil surface, b) soil covered, herbicide applied to plant and rinsed-off foliage and onto soil after 24 or 72 h, c) soil covered, herbicide applied to plant and rinsed-off foliage at 24 or 72 h and kept from soil contact, and d) herbicide applied simultaneously to plant and soil. DPX-PE350 was applied at 140 g ha^{-1} to two- to three-leaf plants with a mechanical spray chamber operating at conditions described previously. Soil moistures were adjusted 1 wk before herbicide application by watering daily to a predetermined weight which was based on a moisture release curve for Etowah silt loam. Soil moistures were maintained throughout the experiment by hand watering daily from the top, and care was taken not to wet the foliage. To achieve selective application, small plastic cups were used to cover foliage or plastic beads covered the soil surface at spraying and were removed after spraying. For the appropriate plants, foliage was rinsed at 24 or 72 h with 50 ml water using a plastic bottle with a syringe attachment. Treatments were replicated three times. Velvetleaf were evaluated for visual injury and fresh weight reduction 2 wk after herbicide application.

Statistical analyses. Data were analyzed using the General Linear Models procedure (11). All experiments were analyzed as completely randomized designs. Analyses indicated no significant run effect where experiments were repeated, therefore data were combined across runs. Simple regression equations involving quadratic and/or linear components were generated to describe data in GR_{50} and effect of rainfall experiments. For the soil moisture/root uptake experiment, means of significant treatment effects were separated using Fisher's Protected LSD test at the 5% probability level.

RESULTS AND DISCUSSION

GR_{50} experiments. Velvetleaf fresh weights were reduced approximately 50% by 70 g ha^{-1} DPX-PE350 at 3 WAT (Figure 1). A linear-quadratic equation empirically described fresh weight reduction with increasing rate. Maximum fresh weight reduction (63%) was obtained with 140 g ha^{-1}.

A 50% reduction in fresh weight was not obtained with cotton or sicklepod at any DPX-PE350 rate in these experiments (Figure 2). Linear equations described cotton and sicklepod fresh weight reduction from increasing rates

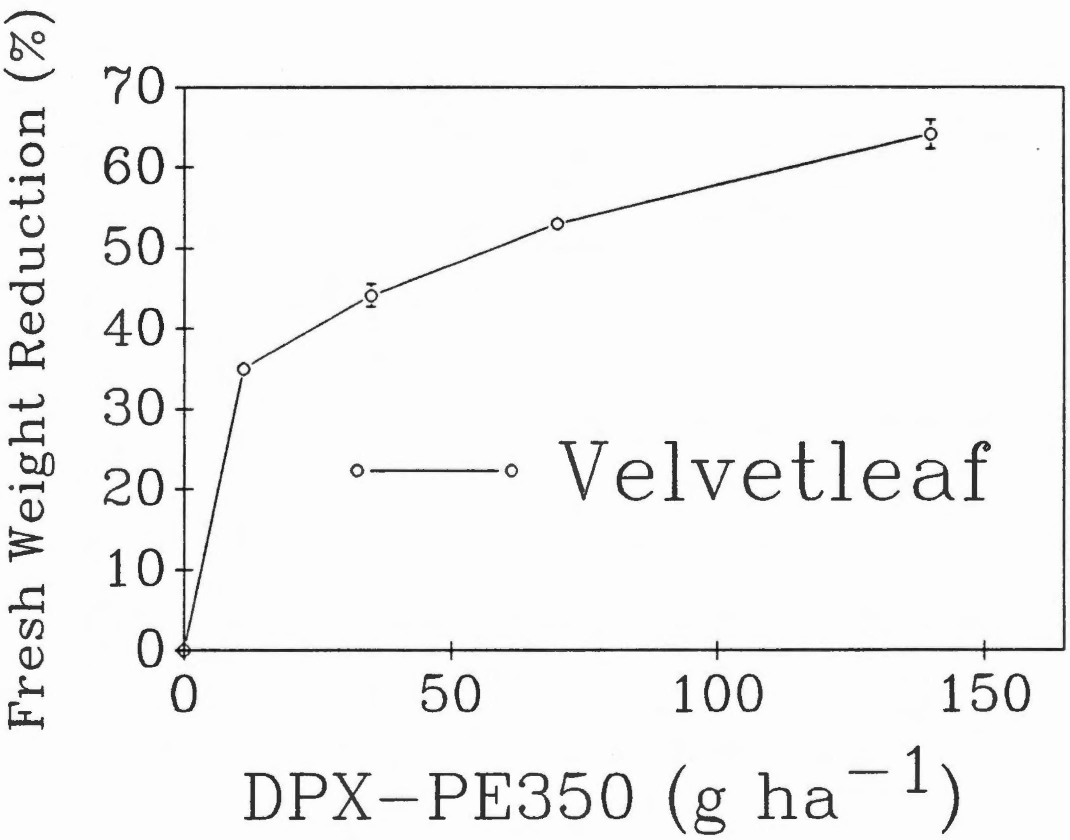

Figure 1. Velvetleaf fresh weight reduction at increasing rates of DPX-PE350. Data are a plot of the equation: $Y = 30.975 + 0.402 * Rate - 0.001 * Rate^2$; $r^2 = 0.91^{**}$, P=0.01.

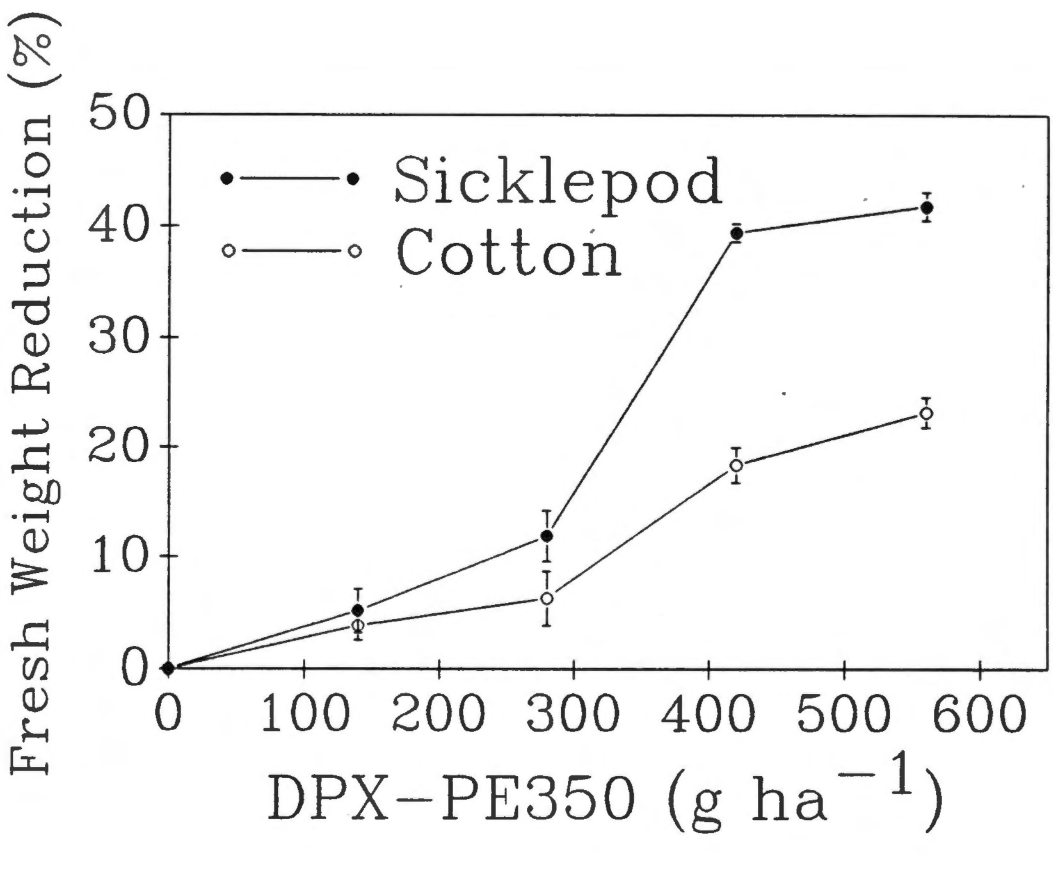

Figure 2. Cotton and sicklepod fresh weight reduction at increasing rates of DPX-PE350. Cotton data are a plot of the equation: Y= -4.75 + 0.050 * Rate; r^2= 0.71**, P= 0.01. Sicklepod data are a plot of the equation: Y= -9.813 + 0.098 * Rate; r^2= 0.83**, P= 0.01.

of DPX-PE350. Cotton was tolerant to most rates of DPX-PE350 and had <30% fresh weight reduction at 560 g ha^{-1}.

Sicklepod fresh weights were reduced 40 to 43% by DPX-PE350 at 420 or 560 g ha^{-1} (Figure 2). A GR_{50} rate for sicklepod might have been determined if higher rates of DPX-PE350 had been included. However, rates above 560 g ha^{-1} would be >6 times the targeted use rate (8) and information would not be of practical use.

Results from these experiments indicate that under growth chamber conditions DPX-PE350 has good cotton safety and excellent activity on velvetleaf, but only limited activity on sicklepod at projected use rates of 70 to 140 g ha^{-1}. These data are consistent with results obtained in field experiments. Field data indicate that DPX-PE350 is safe to cotton when applied postemergence and provides excellent velvetleaf control (8). Sicklepod is controlled more by soil-applied DPX-PE350 than by foliar-applied DPX-PE350 (8, 10).

Effect of rainfall. The time between DPX-PE350 application and 5 mm of simulated rainfall affected velvetleaf injury 4 WAT and was described by a linear equation (70 g ha^{-1}) or a linear-quadratic equation (140 g ha^{-1}) (Figure 3). Velvetleaf was most injured (68%) from 140 g ha^{-1} DPX-PE350 washed-off after a 5 h delay. Data were more variable at the 70 g ha^{-1} rate, however rainfall prior to 5 h had a greater effect on velvetleaf response at 70 g ha^{-1} DPX-PE350

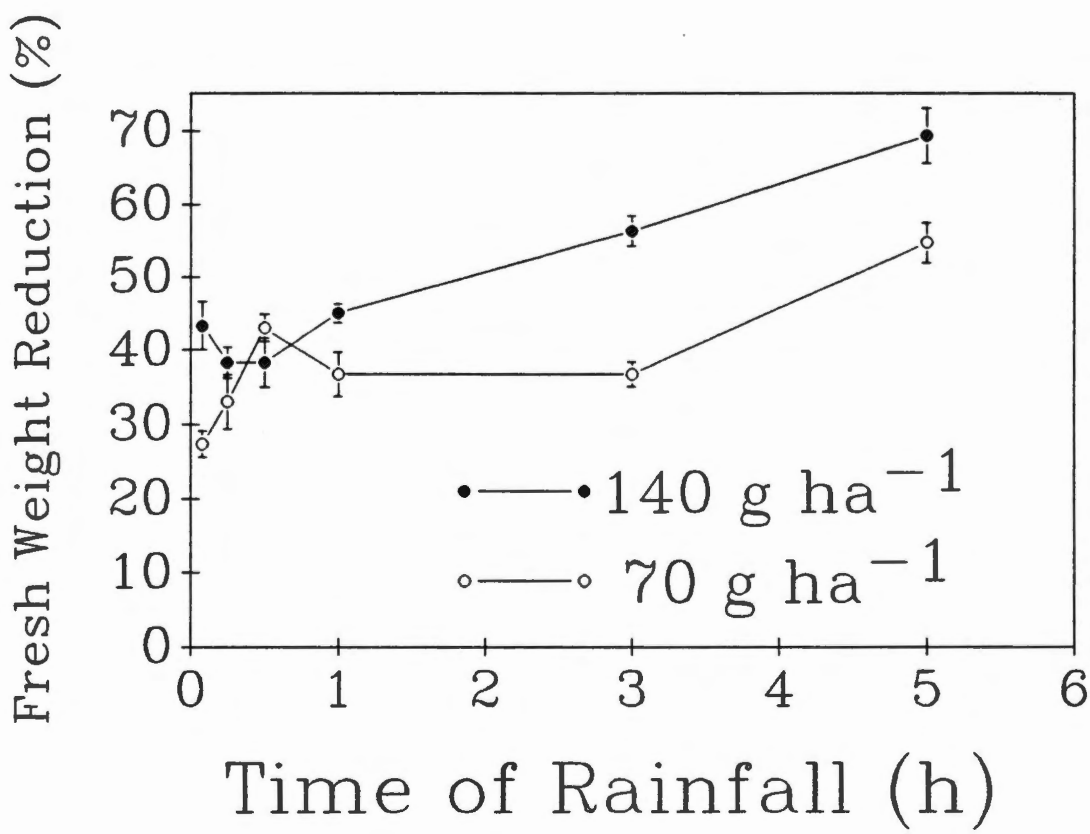

Figure 3. Velvetleaf fresh weight reduction from DPX-PE350 applied at 70 or 140 g ha^{-1} and washed off foliage at various times. Data for DPX-PE350 at 70 g ha^{-1} are described by the equation: Y= 35.286 + 1.822 * Time; r^2= 0.77**, P= 0.01. DPX-PE350 applied at 140 g ha^{-1} are described by: Y= 38.042 + 7.160 * Time - 0.226 * Time^2; r^2 =0.83**, P= 0.01.

than at 140 g ha^{-1}.

There was 20 to 30% fresh weight reduction when 0.08 h lapsed between herbicide application and the rainfall event (Figure 3). Fresh weight reduction after only 0.08 h exposure to DPX-PE350 might indicate that an injurious dose was absorbed in the first 0.08 h of exposure, or that DPX-PE350 was washed-off the foliage into the soil where it was available for root uptake. Mitchell (8) reported that DPX-PE350 is rapidly absorbed by both foliage and roots of susceptible plants. Possibly DPX-PE350 was only partially removed by the rainfall event. Buchanan, et al.,(3) reported that a rainfall event as early as 0.25 h did not significantly reduce the activity of the sulfonylurea herbicide,
DPX-A7881.

These results indicate that when a light rainfall event occurs within 5 h of DPX-PE350 application, some reduction in velvetleaf activity occurs. There is potential for loss of activity in the field, particularly when 70 g ha^{-1} or less DPX-PE350 is applied.

Soil moisture, root uptake and DPX-PE350 efficacy.
Velvetleaf was injured more when DPX-PE350 was applied to plants growing at a soil moisture of -0.03 MPa (Table 1). Injury to velvetleaf when foliage was covered and DPX-PE350 was applied to soil only occurred when moisture levels were near field capacity (-0.03 MPa). No effect from soil-

Table 1. Effect of soil moisture and site of application on DPX-PE350 injury to velvetleaf.

Site Of Application[b]	Weight Reduction[a]	
	Soil Moisture	
	-0.03 MPa	-1.0 MPa
	--------%--------	
1. Foliage and soil	68	30
2. Foliage only + washed[c] onto soil after 24 h	49	15
3. Foliage only + washed onto soil after 72 h	62	28
4. Foliage only, washed at 24 h, no soil contact	49	14
5. Foliage only, washed at 72 h, no soil contact	54	35
6. Soil only, no herbicide on foliage	24	0
LSD (0.05) within moistures	11	13
LSD (0.05) overall	6.1	

[a]Fresh weight reduction is based on comparison to untreated plants.

[b]Where herbicide was directed to either soil or foliage, plants were covered with plastic cups or soil was covered with plastic beads.

[c]Plants were washed using a plastic bottle with a syringe attachment to run 50 ml water over the foliage. Herbicide was kept from soil contact using a plastic wrap barrier.

applied DPX-PE350 was observed when soil was dry (-1.0 MPa).

The largest reduction in velvetleaf fresh weight occurred when DPX-PE350 was applied simultaneously to foliage and soil (Table 1) as would occur with a postemergence application. Rinsing treated foliage at 24 h or 72 h and applying rinse water to soil caused greater fresh weight reduction than when rinse water was not applied to soil, although these differences were not statistically significant.

Most DPX-PE350 activity on velvetleaf appears to be due to foliar absorption, and most foliar absorption appears to be occurring by 72 h. Injury from soil-applied and foliar-applied DPX-PE350 was not additive, but DPX-PE350 on soil appears to contribute to overall activity in plants grown in the growth chamber. Plants were grown in small containers and watered daily from the top. These conditions would promote root uptake from over the top DPX-PE350 applications.

Soil uptake from over the top applications would probably contribute to DPX-PE350 activity in the field. Field data indicate that DPX-PE350 has limited activity on certain weeds as a soil-applied herbicide (10). Soil uptake would increase or provide some residual weed control.

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PART IV

TEMPERATURE AND SOIL MOISTURE EFFECT ON COTTON AND VELVETLEAF RESPONSE TO DPX-PE350

ABSTRACT[1]

Growth chamber experiments were conducted to evaluate the effect of ambient temperature and soil moisture on cotton and velvetleaf response to DPX-PE350. Additional studies were performed using ^{14}C DPX-PE350 to determine the basis for observed plant responses. Cotton injury was <20% at 2 wk for all temperatures and soil moistures. DPX-PE350 injured velvetleaf less at lower soil moistures. Both species absorbed more ^{14}C-DPX-PE350 at 30/28 or 35/33 C than at 25/23 C. Cotton absorbed more herbicide than velvetleaf at all temperatures and soil moistures but translocated less than 2% of absorbed material. Velvetleaf translocated up to 12% of absorbed ^{14}C out of the treated leaf. At warmer temperatures, velvetleaf absorbed and translocated less ^{14}C when soil was dry (-1 MPa) than when plants were watered to field capacity (-0.03 MPa). This decrease in absorption and translocation may affect DPX-PE350 activity on velvetleaf growing in dry soil. **Nomenclature:** DPX-PE350, sodium 2-chloro-6-(4,5-dimethoxy-pyrimidin-2-ylthio)-benzoate;

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[1]To be submitted for publication in *Weed Science*. Authors: M. Angela Harrison, Robert M. Hayes, Thomas C. Mueller. Former Grad. Res. Asst., Prof., and Asst. Prof., respectively, Dept. of Plant and Soil Sci., Univ. of Tennessee, Knoxville, TN 37901. Current address of senior author: 3107 Salem Road, Milan, TN 38358.

velvetleaf, *Abutilon theophrasti* Medik #[2] ABUTH; cotton, *Gossypium hirsutum* L 'Deltapine 50'.

Additional index words. *Abutilon theophrasti*, *Gossypium hirsutum*, ABUTH, GOSHI, growth chamber, ambient temperature, soil moisture, absorption, translocation, metabolism, herbicide, sodium salt of pyrithiobac.

INTRODUCTION

DPX-PE350 is a potential herbicide for over-the-top broadleaf weed control in cotton. Prospective use rates are <200 g ai ha^{-1} (12). Researchers have obtained control of troublesome weeds like velvetleaf, and minimal cotton injury using DPX-PE350 (7, 12, 14). DPX-PE350 acts by inhibiting acetolactate synthase (ALS), the enzyme catalyzing an essential step in the synthesis of branched- chain amino acids (12). The rate of DPX-PE350 metabolism is the basis for selectivity in sensitive versus tolerant *Ipomoea* species (17). This is the selectivity mechanism of other herbicides which inhibit ALS (1, 20).

Temperature, rainfall, light intensity, and relative humidity can affect the phytotoxicity of foliar herbicides (6). Many herbicides inhibit specific plant processes. If

[2]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

plants are growing under stressed conditions and those processes are affected, then herbicide activity will be decreased. Sims et al., (16) partially attributed a decrease in DPX-PE350 postemergence activity on velvetleaf to field environmental conditions at the time of herbicide application.

Environmental conditions may affect herbicide activity by influencing changes in absorption. Diffusion through the cuticle may be a temperature-dependant process (2, 15). Warm temperatures before and after spraying increase the penetration of some herbicides (10, 13).

Soil moisture affects the field performance of some herbicides (4, 11). Decreased absorption and translocation reduces herbicide concentrations in drought stressed plants (9, 18). Herbicide penetration may be altered by changes in cuticle thickness or composition in certain plants grown under low soil moisture (3, 19). The translocation of photosynthate may change under moisture stress (8).

The behavior of DPX-PE350 in velvetleaf and cotton following postemergence application have not been examined. The objectives of this research were to examine the influence of soil moisture and ambient temperature on control of velvetleaf and injury to cotton with DPX-PE350 and to determine the influence of temperature and soil moisture on absorption and translocation of DPX-PE350 in cotton and velvetleaf.

MATERIALS AND METHODS

Environmental effect on DPX-PE350 efficacy and phytotoxicity. Seeds of cotton and velvetleaf were planted in separate 10 cm diameter styrofoam pots which were perforated for drainage and filled with 400 g of surface soil from the Etowah silt loam series (fine-loamy, siliceous, thermic typic Paleudults). Greenhouse conditions were 35 to 22 C ambient temperature and 50 to 80% relative humidity. Plants were watered once or twice daily as needed with an overhead irrigation system. Seedlings were thinned to one cotton or three velvetleaf plants per pot 1 wk after planting. A liquid fertilizer solution was applied to each pot before pots were moved to the growth chamber.

Plants were transferred to the growth chamber 1 wk prior to herbicide application for preconditioning to temperature and soil moisture. Treatments were arranged in a complete factorial, replicated three times within the experiment. Treatments were day/night temperatures of 25/23, 30/28, or 35/33 C, soil moistures of -0.03, -0.5, or -1 MPa, and DPX-PE350 at 0, 70 or 140 g ha^{-1} to velvetleaf and 0, 140 or 420 g ha^{-1} to cotton. Herbicide treatments contained 0.25% (v/v) non-ionic surfactant[3]. Light

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[3]X-77 (alkylaryl-polyoxyethylene glycols, free fatty acids, and isopropanol). Valent U.S.A. Corp., 1333 North California Blvd., Walnut Creek, CA 94596.

intensity (620 $uMol\ m^{-2}\ s^{-1}$) in a 12 hr photoperiod and relative humidity (60%) were held constant. Each temperature regime was examined in a separate experiment in the growth chamber. The same growth chamber was used for each experiment. Soil moisture was adjusted daily by watering to a predetermined weight, which was based the moisture release curve for Etowah silt loam. Temperature regimes and soil moistures were maintained until plants were harvested.

DPX-PE350 was applied to plants which were at the three- to four-leaf stage with a CO_2 pressurized mechanical spray chamber equipped with a flat-fan even-spray nozzle[4] delivering 190 L ha^{-1} at 260 kPa. Plants were removed from the growth chamber for spraying and then returned to the growth chamber in a procedure which took less than 5 min.

Visual injury was evaluated 2 wk after herbicide application, on a scale of 0 to 100 with 0 equal to no injury and 100 corresponding to plant death. Foliar chlorosis and stunting were considered when determining visual injury. At this time, plants were cut at the soil surface and fresh weights and plant heights were recorded.

Data from the three temperature regimes were combined and analyzed as a completely randomized design. Fresh weight and visual injury data were converted to a percentage

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[4]TeeJet 8001E tip. Spraying Systems Co., Wheaton, IL 60187.

of nontreated controls. Percentage data did not benefit from arc sin transformation, therefore results presented are based on analysis of non transformed data. Mean separation was conducted without the nontreated control. Means of significant main effects and interactions were separated with Fisher's Protected LSD Test (P=0.05). Plant height data showed less measurable response differences since DPX-PE350 is a slow acting herbicide and evaluations were made at 2 wk, therefore only fresh weight and visual injury data are presented.

^{14}C-DPX-PE350 experiments. Cotton and velvetleaf were grown in the greenhouse and transferred to the growth chamber and watering and preconditioning were accomplished as previously described. Treatments included the three day/night temperature regimes described above and soil moistures of -0.03 or -1 MPa. Light intensity and relative humidity were constant at levels described previously.

^{14}C-DPX-PE350 (2.2×10^3 Bq) was applied as ten 1 ul droplets around the midvein of the second true-leaf of cotton and the third true-leaf of velvetleaf. Treated leaves were marked at the tip with a permanent laboratory marker for identification purposes during the experiment. Plants were oversprayed with 140 g ha^{-1} formulated DPX-PE350. Radiolabeled herbicide and formulated spray solutions contained 0.25% (v/v) non-ionic surfactant[3]. Plants were removed from the growth chamber for ^{14}C-DPX-PE350 application and overspraying in a procedure which took <15 min. Treatments were replicated three times in a completely randomized design and nontreated plants were included for comparison. ^{14}C-DPX-PE350 was ring-labelled [phenyl-2-^{14}C] and had a specific activity of 1.368×10^6 Bq/mg.

Plants were harvested 6, 24, or 72 h after treatment (HAT) by sectioning into treated leaf, shoot and root. Treated leaves were washed initially in 10 ml water and then in 10 ml methanol to remove unabsorbed ^{14}C-DPX-PE350. This was accomplished by placing treated leaves into a 20 ml scintillation vial containing either water or methanol and shaking the vial briskly for 30 s before removing the treated leaf. Three and 5 ml aliquots were added to 15 and 10 ml of scintillation cocktail[5] for water and methanol washes, respectively. ^{14}C was detected by liquid scintillation spectroscopy and corrected for quench effects. Roots were gently rinsed with water to remove any soil. Plant sections were oven dried at 60 C for 72 h and weighed.

Plant parts were combusted in a biological tissue oxidizer[6]. $^{14}CO_2$ was collected in 18 ml of scintillation fluid[7] and assayed using liquid scintillation spectroscopy.

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[5]ScintiVerse BD (water washes) and ScintiVerse II (methanol washes). Fisher Scintific, Fair Lawn, NJ 07410.

[6]Packard Tri-Carb Oxidizer. Packard Instrument Co., Downers Grove, IL 60515.

[7]Carbo-Sorb and Permafluor. Packard Instrument Co., Meridian, CT 06450.

^{14}C content in plant sections was calculated on a dry weight basis (Appendix A).

Data for the three temperature regimes were combined and analyzed as a completely randomized design. ^{14}C absorption was expressed as a percentage of applied ^{14}C-DPX-PE350. ^{14}C retained in treated leaf and translocated from treated leaf were converted to a percentage of absorbed ^{14}C and were analyzed after arcsine transformation. Arcsine transformation was used only where it improved the analysis and mean separation of data. Means of significant treatment effects were separated using Fisher's Protected LSD Test (P=0.05).

RESULTS AND DISCUSSION

Environmental effect on DPX-PE350 efficacy and phytotoxicity. DPX-PE350 at 420 g ha^{-1} caused <20% visual injury and fresh weight reduction in cotton at 2 wk (Table 2). There was no clear temperature or soil moisture effect on cotton injury at either 70 or 140 g ha^{-1} DPX-PE350, although fresh weight reduction was slightly less at 30/28 C and at the dry soil moisture treatment (-1 MPa) at 25/23 or 35/33 C (Table 1 and 2). DPX-PE350 at 140 g ha^{-1}, which is closer to the targeted use rate, caused <10% visual injury and no significant fresh weight reductions (Table 1).

Table 1. Cotton injury at 2 wk from DPX-PE350 applied at 140 g ha^{-1}.

Soil Moisture	Visual Injury Temperature Regime 25/23 C	 30/28 C	 35/33 C
MPa	%		
-0.03	4	3	3
-0.5	0	0	3
-1.0	0	0	0
LSD (0.05)	NS	NS	NS

Soil Moisture	Weight Reduction Temperature Regime 25/23 C	 30/28 C	 35/33 C
MPa	%		
-0.03	0	0	1
-0.5	1	0	2
-1.0	0	0	0
LSD (0.05)	NS	NS	NS

Table 2. Cotton injury at 2 wk from DPX-PE350 applied at 420 g ha^{-1}.

	Visual Injury		
	Temperature Regime		
Soil Moisture	25/23 C	30/28 C	35/33 C
MPa	---------------%	-----------------	
-0.03	7	7	13
-0.5	3	7	10
-1.0	7	0	10
LSD (0.05)	NS	6	NS
	Weight Reduction		
	Temperature Regime		
Soil Moisture	25/23 C	30/28 C	35/33 C
MPa	-----------------%	-----------------	
-0.03	19	0	16
-0.5	14	10	17
-1.0	4	10	0
LSD (0.05)	NS	10	12

Some researchers[8] have observed that DPX-PE350 may cause greater injury to cotton plants growing under cool, wet, and cloudy field conditions. Metabolism has been identified as the basis for DPX-PE350 selectivity in some morningglory species (17). Poor growing conditions would decrease metabolic rates resulting in herbicide injury. Temperatures of 25/23 C may not have been cool enough to influence cotton injury. Also, light intensity was maintained at a high level (620 uMol m^{-2} s^{-1}) and this may have offset any cool temperature effects.

At 35/33 C and -1 MPa moisture, visual injury of 10% (Table 2) from 140 g ha^{-1} DPX-PE350 did not result in fresh weight reduction because foliar chlorosis was considered as well as stunting when making visual injury evaluations.

DPX-PE350 was active on velvetleaf at 25/23 C when plants were watered to field capacity (-0.03 MPa) or moderately dry (-0.5 MPa) (Table 3 and 4). This would indicate potential for use as an early postemergence treatment in spring when temperatures may still be relatively cool.

DPX-PE350 at 140 g ha^{-1} reduced velvetleaf fresh weights at all temperatures (Table 4). Moisture stressed plants exhibited less herbicide injury and fresh weight reduction, indicating herbicide activity decreased

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[8]C.S. Williams and W. Mitchell, personal communication.

Table 3. Velvetleaf injury at 2 wk from DPX-PE350 applied at 70 g ha^{-1}.

	Visual Injury		
	Temperature Regime		
Soil Moisture	25/23 C	30/28 C	35/33 C
MPa	----------------	%	----------------
-0.03	77	70	48
-0.5	47	37	45
-1	27	13	17
LSD (0.05)	14	11	15

	Weight Reduction		
	Temperature Regime		
Soil Moisture	25/23 C	30/28 C	35/33 C
MPa	----------------	%	----------------
-0.03	49	53	34
-0.5	31	29	16
-1.0	0	11	7
LSD (0.05)	12	13	9

Table 4. Velvetleaf injury at 2 wk from DPX-PE350 applied at 140 g ha^{-1}.

	Visual Injury		
	Temperature Regime		
Soil Moisture	25/23 C	30/28 C	35/33 C
MPa	-------------------	%	-------------------
-0.03	85	90	87
-0.5	78	62	60
-1	33	27	23
LSD (0.05)	15	8	15
	Weight Reduction		
	Temperature Regime		
Soil Moisture	25/23 C	30/28 C	35/33 C
MPa	-------------------	%	-------------------
-0.03	70	69	48
-0.5	54	68	19
-1.0	10	60	18
LSD (0.05)	18	8	18

with a decrease in soil moisture.

Reduction of velvetleaf fresh weight by DPX-PE350 was not as great at the high temperature (Table 3 and 4). Fresh weights for nontreated plants were lower than weights of nontreated plants grown at medium or low temperatures, indicating velvetleaf plants may have been stressed due to high temperature. Since plants of the same growth stage were used in all experiments, these weight differences were not the result of treating different aged plants.

Data analysis indicated significant temperature by moisture interactions with cotton fresh weight reduction (P=0.01) and significant temperature by moisture by rate interactions with velvetleaf fresh weight and visual injury, (P=0.01) therefore, data were not combined over temperature, moisture treatment, or DPX-PE350 rate.

^{14}C-DPX-PE350 Experiments. Recovery of ^{14}C-DPX-PE350 averaged >90%. Cotton absorbed more herbicide than velvetleaf at all temperatures and soil moistures (Figure 1). At 72 h and 25/23 C cotton and velvetleaf absorbed less total ^{14}C-DPX-PE350 than at 30/28 or 35/33 C when moisture was -0.03 MPa. Moisture stressed conditions caused a decrease in absorption at 30/28 C and 35/33 C of 10 to 19% in cotton and 3 to 10% in velvetleaf (Figure 1). Soil moisture stress did not decrease herbicide absorption at low temperature.

Cotton and velvetleaf translocated <12% of absorbed ^{14}C

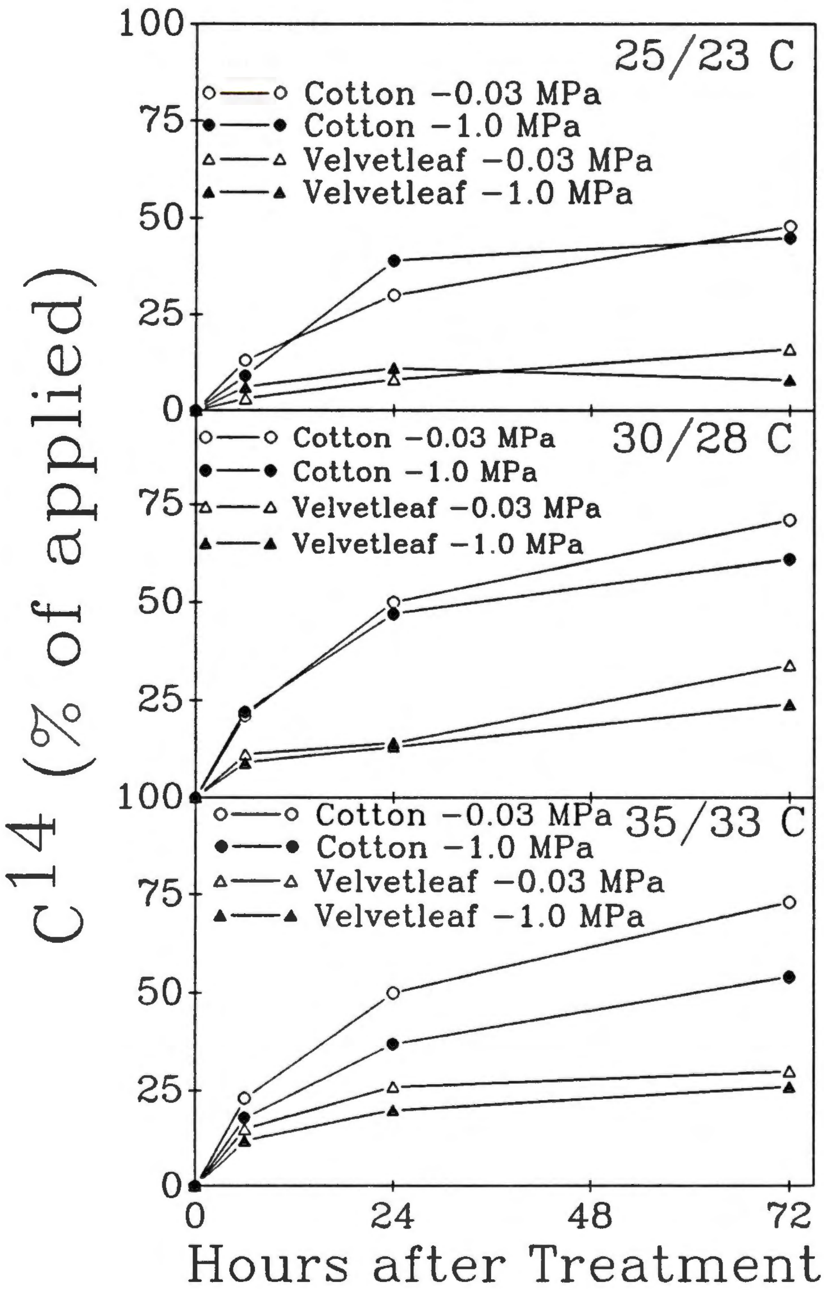

Figure 1. Absorption of ^{14}C-DPX-PE350 at 6, 24 and 72 h by cotton and velvetleaf as a function of soil moisture and ambient temperature.

out of the treated leaf at 72 h (Figure 2). Translocation was limited to the shoot since <1% of absorbed ^{14}C-label was detected in plant roots at 72 h (data not shown). Velvetleaf translocated more herbicide from the treated leaf than cotton at all temperatures and moistures (Figure 2).

Cotton translocated <3% of absorbed ^{14}C from the treated leaf at 72 h (Figure 2). There was no soil moisture or temperature effect on translocation of absorbed herbicide from cotton leaves. Cotton plants may be metabolising DPX-PE350 to non-mobile products which are retained in the leaf by conjugation or other means.

Velvetleaf translocated the greatest amount of herbicide (10.3%) under low temperature and moist soil conditions (Figure 2). Moisture stress at the two warmer temperatures caused a small decrease in translocation in velvetleaf, although these differences were not statistically significant.

The decrease in DPX-PE350 activity on velvetleaf under soil moisture stress observed in previous growth chamber experiments may be only partially attributed to slight decreases in absorption and translocation under moisture stress at the two warmer temperature regimes. Velvetleaf absorbed less ^{14}C label at the cool temperature but translocated more ^{14}C label when soil moisture was -0.03 MPa which may partially explain the good herbicide activity observed at 25/23 C and -0.03 MPa soil moisture.

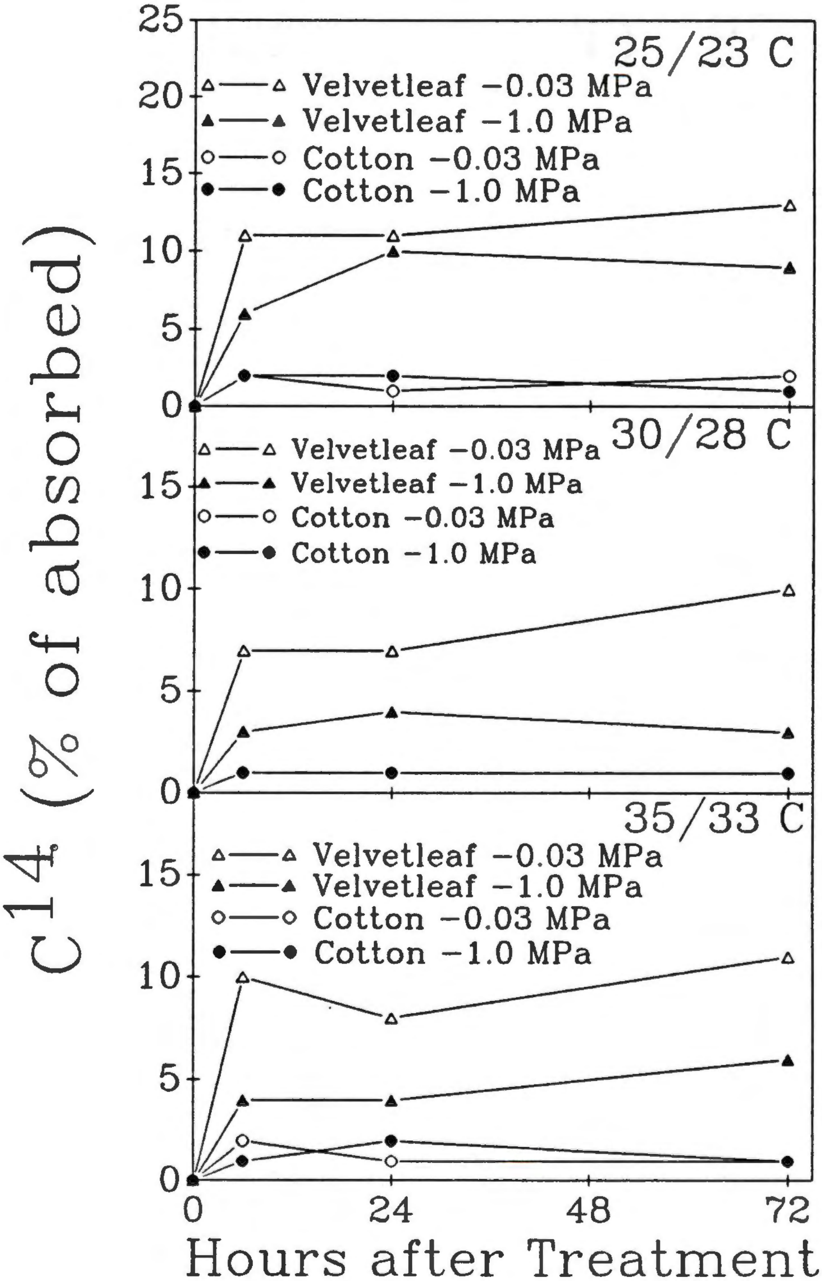

Figure 2. Translocation of ^{14}C-DPX-PE350 label out of the treated leaf at 6, 24 and 72 h by cotton and velvetleaf as a function of soil moisture and ambient temperature.

Herbicide activity on velvetleaf from foliar-applied DPX-PE350 may be the result of both root uptake and foliar absorption. The decline in DPX-PE350 activity on velvetleaf at the dry soil moisture treatment can not be simply explained by absorption or translocation differences. Less root uptake is likely when soil is dry and herbicide isbound to soil. Plants growing in dry soil may have slower metabolic and growth rates. DPX-PE350 inhibition of ALS would be less detrimental to a slower growing plant. Further studies are needed to determine if decreased ALS inhibition is the basis for activity decrease under dry soil conditions.

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PART V

GENERAL SUMMARY

Results from these experiments indicate that cotton is tolerant to foliar-applied DPX-PE350 across a wide range of herbicide rates, ambient temperatures, and soil moistures. Cotton tolerance appears to be due to limited translocation which may be the result of rapid metabolism to non-mobile products. DPX-PE350 is active on velvetleaf at rates of less then 140 g ai ha^{-1} across a range of temperatures. However, activity decreased when DPX-PE350 was applied to velvetleaf growing in very dry soil, indicating a potential control problem in drought-stressed fields. Additionally, a rainfall event within 5 h after DPX-PE350 application reduces activity of DPX-PE350 on velvetleaf, particularly when applied at 70 g ha^{-1}.

Herbicides which provide safe and effective postemergence broadleaf weed control are needed in cotton weed management systems. DPX-PE350 will provide growers with an alternative to soil-applied and post-directed herbicides, thereby allowing more flexibility in weed management practices and choice of tillage system.

APPENDIX

Table 1. ^{14}C-DPX-PE350 label detected in cotton and velvetleaf at 6, 24, 72 h.

			^{14}C Label								
			Temperature Regime								
			25/23 C			30/28 C			35/33 C		
Species	Part	Moisture	6 h	24 h	72 h	6 h	24 h	72 h	6 h	24 h	72 h
		MPa	------------------ug ^{14}C g^{-1} dry weight----------------								
Cotton	Leaf[a]	-0.03	1.7	7.4	7.4	3.1	6.8	9.9	6.3	13.9	21.4
		-1.0	2.1	10.9	14.6	7.0	16.9	16.0	9.2	17.5	24.1
	Shoot	-0.03	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
		-1.0	ND	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Root	-0.03	ND	ND	ND	ND	ND	ND	<0.1	ND	ND
		-1.0	ND	ND	ND	ND	ND	ND	ND	ND	<0.1
Velvetleaf	Leaf	-0.03	1.4	5.0	5.2	5.2	7.2	17.0	5.9	14.7	18.3
		-1.0	6.0	7.0	14.8	6.8	14.9	34.9	22.9	32.1	36.0
	Shoot	-0.03	<0.1	<0.1	0.14	<0.1	0.17	0.40	0.17	0.40	0.42
		-1.0	0.14	0.45	0.40	<0.1	0.22	0.26	0.15	0.33	0.64
	Root	-0.03	ND	ND	<0.1	ND	ND	ND	ND	ND	<0.1
		-1.0	ND	ND	<0.1	ND	ND	ND	ND	ND	ND
LSD(0.05)			----------------------4.1----------------------								

[a]Leaf denotes treated leaf. ND denotes none detected.

VITA

Mary Angela (Thompson) Harrison was born in Chicago, Illinois on July 27, 1963. She graduated from Fancy Farm High School in Fancy Farm, Kentucky in May 1981 and entered Murray State University, Murray, Kentucky. Her Bachelor of Science degree in Agriculture was completed in May 1985. In January 1987, she entered the University of Kentucky, Lexington, as a Graduate Research Assistant in the Agronomy Department. She received her Master of Science degree with a major in Weed Science in May 1989. Following a six month internship with Monsanto Agricultural Chemicals Company, she began work toward the Doctor of Philosophy at the University of Tennessee, Knoxville in the Department of Plant and Soil Science. She received her Ph.D. in August 1993 with an emphasis in Weed Science.

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