ABSTRACT

PRICE, ANDREW JENNINGS. Performance of diclosulam in conventional and strip-tillage peanut; physiological behavior of flumioxazin in cotton, peanut, and selected weeds; performance of flumioxazin in cotton; and morningglory response to neighboring plants and structure. (Under the direction of Dr. John W. Wilcut.)

Research evaluated new herbicides to improve weed management in conventional and minimum-tillage production in cotton and peanut, herbicide physiology in cotton, peanut, and selected weeds, and morningglory response to neighboring plants and objects. Diclosulam preemergence (PRE) plus metolachlor PRE in conventional and strip-tillage peanut production usually controlled common lambsquarters, common ragweed, eclipta, prickly sida, and entireleaf morningglory. However, control of spurred anoda, goosegrass, ivyleaf morningglory, large crabgrass, and pitted morningglory by this system was inconsistent and may require additional POST herbicide treatments. Flumioxazin applied preplant (PP) at 71 or 105 g ai/ha tank mixed with the isopropylamine salt of glyphosate at 1.12 kg ai/ha, paraquat at 1.05 kg ai/ha, or with the trimethylsulfonium salt of glyphosate at 1.12 kg ai/ha controlled common chickweed, common lambsquarters, common ragweed, Palmer amaranth, and smooth pigweed ≥ 96% at 29 to 43 days after treatment. Differential absorption, translocation, and metabolism at various growth stages, as well as the development of a bark layer, are the bases for differential tolerances of cotton at different growth stages to flumioxazin applied as a postemergence-directed spray. Flumioxazin is shown to be a safe herbicide for use in cotton PP 28 days before planting on similar soils to those found in studies in North Carolina. These data also support the flumioxazin PP label for burndown uses at 71 g/ha at least 30 days before planting cotton. The inclusion of a residual herbicide such as flumioxazin in a PP treatment should reduce early season weed interference in production systems that do not use herbicides or tillage at planting to control weeds.

Morningglories initial planting distance from structures as well as the structures spectral reflectance influenced the percentage of ivyleaf morningglory that exhibited climbing growth as well as their final weight. Mornigglory final weight influenced the number of seeds produced per plant. Ivyleaf morningglory tended to respond to spatial distribution of surrounding objects and apparently used reflectance to preferentially project their stems toward the most prospective structure for climbing. Flumioxazin treatments containing either water dispersible granular (WDG) or wettable powder (WP) formulation at 1.4 μmol/L did not influence germination compared to non-treated peanut across all temperature regimes. Peanut treated with a WDG or a WP formulation of flumioxazin PRE and receiving irrigation at emergence and at 2 and 4 d after emergence were injured between 40 and 60%, while peanut treated at 8 and 12 d after emergence were injured between 25 and 15%, respectively. Total ^{14}C absorbed by ivyleaf mornigglory was 57% of applied while sicklepod absorbed 46%, at 72 hours after treatment (HAT). Peanut absorbed > 74% of applied ^{14}C 72 HAT. A majority of absorbed ^{14}C remained in roots for sicklepod, ivyleaf morningglory, and peanut at all harvest times. Ivyleaf morningglory contained 41% of the parent herbicide 72 HAT while sicklepod and peanut contained only 24 and 11% parent compound, respectively. Regression slopes indicated slower metabolism by ivyleaf morningglory compared to sicklepod and peanut.

PERFORMANCE OF DICLOSULAM IN CONVENTIONAL AND STRIP-TILLAGE PEANUT; PHYSIOLOGICAL BEHAVIOR OF FLUMIOXAZIN IN COTTON, PEANUT, AND SELECTED WEEDS; PERFORMANCE OF FLUMIOXAZIN IN COTTON; AND MORNINGGLORY RESPONSE TO NEIGHBORING PLANTS AND STRUCTURE.

by

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BIOGRAPHY

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CHAPTER 1

Literature Review

Weed management in peanut (*Arachis hypogaea* L.) traditionally requires soil-applied preplant incorporated (PPI) or preemergence (PRE) herbicide treatments followed by (fb) multiple applications of early-postemergence (EPOST) and postemergence (POST) herbicide combinations (Bailey et al. 1999a; Bridges et al. 1994; Wilcut et al. 1994). Annual grasses, common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), common cocklebur (*Xanthium strumarium* L.), *Ipomoea* species, *Amaranthus* species, and yellow nutsedge (*Cyperus esculentus* L.) are some of the most common weeds found in peanut production in the Southeast U.S. (Bridges et al. 1994). Control of this weed complex requires multiple herbicide treatments (Askew et al. 1999; Bailey et al. 1999a, 1999b; Wilcut and Swann 1990; Wilcut et al. 1991; York et al. 1995)

Soil applied herbicides registered for application in Southeastern U.S. peanut include diclosulam, dimethenamid, ethalfluralin, flumioxazin, imazethapyr, metolachlor, and pendimethalin. Ethalfluralin and pendimethalin PPI control annual grasses and small-seeded broadleaf weeds; however, they do not control large-seeded broadleaf weeds commonly found in Southeastern U.S. peanut fields including common ragweed, eclipta (*Eclipta prostrata* L.), annual *Ipomoea* species, and prickly sida (Askew et al. 1999; Bridges et al. 1994; Wilcut and Swann 1990; Wilcut et al. 1990, 1994). These weeds often require multiple applications of POST herbicides for season-long control (Bailey et al. 1999a, 1999b; Wilcut and Swann 1990). Imazethapyr soil-applied or POST does not control common ragweed or eclipta (Wilcut et al. 1991; York et al. 1995).

Approximately 70% of the North Carolina-Virginia peanut hectarage receives a soil treatment of metolachlor which controls annual grasses and provides partial control of common lambsquarters, *Amaranthus* species, and yellow nutsedge (Bridges et al. 1994; Wilcut et al. 1994). A broad-spectrum soil applied herbicide applied in conjunction with metolachlor would be beneficial in the reducing the types and number of herbicides applied and the number of trips through the field (Bailey et al. 1999a, 1999b).

Peanut has typically been grown in ridged conventional-tillage seedbeds (Sholar et al. 1995; Wilcut et al. 1987, 1990, 1994, 1995). Concerns for declining soil organic matter, soil structure degeneration, increased subsoil compaction, and crop damage due to water stress and sandblasting have caused growers to devise ways to reduce tillage operations (Troeh et al. 1991). Strip tillage is a type of conservation tillage where the area within the crop row is tilled while the inter-row areas are not disturbed. This practice reduces soil erosion and evaporative water loss by leaving ≥ 30% crop residues on the soil surface, decreasing soil compaction, and increasing water infiltration (Troeh et al. 1991).

In peanut, herbicide systems are usually more intensive in strip-tillage when compared to conventional tillage because PRE or preplant incorporated within-the-row treatments were expected to provide reduced efficacy compared to conventional PPI treatments (Wilcut et al. 1987). Adequate weed control in minimum tillage requires PRE, EPOST, and POST herbicides (Wilcut et al. 1990). Depending on herbicide system, conventional-tillage peanut produced yields 800 to 1900 kg/ha higher than minimum tillage peanut, and also provided greater net returns (Wilcut et al. 1990). This may be due in part to more effective digging of peanut in conventional systems that are ridged compared to non-ridged minimum tillage peanut (Grichar and Boswell 1987).

Diclosulam is a new triazolopyrimidine sulfonanilide soil applied herbicide recently registered for PPI and PRE treatment in peanut (Anonymous 2000). Ethalfluralin PPI plus diclosulam PPI or PRE has shown activity on a broad spectrum of weeds including common lambsquarters, eclipta, entireleaf morningglory, pitted morningglory, and yellow nutsedge (Bailey et al. 1999a, 1999b, 2000; Baughman et al. 2000; Dotray et al. 2000; Main et al. 2000; Prostko et al. 1998). Peanut cultivars have shown excellent tolerance to diclosulam (Bailey et al. 2000; Main et al. 2000). Since metolachlor is the most commonly used soil applied herbicide in peanut (Bridges et al. 1994), diclosulam needs to be evaluated in metolachlor-based systems. However, no studies have evaluated weed control, crop response, peanut yield, and economic returns from herbicide systems containing diclosulam plus metolachlor PRE. Also, with the recent increase in reduced-tillage peanut production on the mid-Atlantic and Southeastern Coastal Plain and the paucity of data concerning diclosulam performance in reduced-tillage systems necessitates additional research. However, no studies have evaluated weed control, crop response, peanut yield, and economic returns from herbicides systems containing diclosulam in reduced-tillage peanut production.

Many cotton (*Gossypium hirsutum* L.*)* growers in the southeast are utilizing reduced-tillage operations. Reduced-tillage systems are primarily used to address concerns about soil erosion, water availability, and sandblasting of young cotton plants on windy early spring days in sandy soils (Bradley 1995; York 1995). Legumes such as vetch (*Vicia sativa*, L.) or crimson clover (*Trifolium incarnatum,* L.) or small-grains such as wheat or rye (*Secale cereale* L.), are commonly utilized as winter cover in reduced tillage systems and must be desiccated two to three wks before planting (York 1995). Small-grain cover crops are preferred over legumes for no-till cotton because they are easier to establish, easier to kill, provide more protection from soil erosion during the fall and winter months, and provide more persistent mulch and better weed suppression (Naderman et al. 2002). Commonly utilized preplant (PP) burndown treatments in cotton include paraquat and glyphosate-IP (Brown and Whitwell 1985; White and Worsham 1990; York 1995). Both herbicides provide inexpensive winter cover burndown and broad-spectrum weed control (Wilcut et al. 1995). However, neither herbicide effectively controls all weeds and they do not provide residual weed control.

Glyphosate-resistant cotton cultivars are planted on greater than 75% of the North Carolina cotton hectarage (A. C. York, K. Edminsten, North Carolina State University, personal communication). The development of herbicide-resistant cotton cultivars and new herbicides registered for POST application over-the-top of cotton has allowed growers to utilize total POST weed management systems that fit well in reduced tillage operations. Approximately 35 to 40% of North Carolina cotton hectarage does not receive soil-applied herbicide treatments at planting (A. C. York, personal communication). However, the exclusion of residual PRE herbicides at planting allows early-season weed interference which may be detrimental to cotton yield (Askew and Wilcut 1999; Buchanan and Burns 1970; Clewis et al. 2000; Culpepper and York 1998; Scott et al. 2001a). A residual herbicide applied PP in mixture with non-selective herbicides like glyphosate-IP or paraquat could allow flexibility of POST application timings while minimizing early-season weed competition.

Flumioxazin is a *N*-phenylphthalimide herbicide registered for PRE treatment in peanut and as an early-preplant burndown treatment in cotton (Anonymous 2002; Askew et al. 1999; Clewis et al. 2002; Grichar and Colburn 1996). Research indicates that flumioxazin may be applied as a postemergence-directed (PDS) or PP treatment in cotton (Altom et al. 2000;

Askew et al. 2002; Cranmer et al. 2000; Main et al. 2000;Wilcut et al. 2000). Cotton injury due to flumioxazin PP treatments may occur and is influenced by application timing in respect to planting (Askew et al. 2002). Cotton planted no-till into undisturbed cotton and corn stubble was injured ≤ 12% if flumioxazin was applied PRE on the day of planting, but ≤ 3% if application was made at least 2 wks before planting.

Although flumioxazin would appear to be a good fit for PP application alone or in mixture with various PP herbicides in cotton, existing winter cover, cotton, and weed response to these treatments are unknown. However, no studies have evaluated control of an existing wheat cover and weeds with flumioxazin applied PP alone and in mixture with various PP herbicides. Additionally cotton response, kept weed free from the 4-leaf stage to harvest, to flumioxazin PP has not been evaluated. Also, although flumioxazin would appear to be a good fit for PP or PDS applications alone or in mixture with various PP and PDS herbicides in cotton, the effects of rainfall at cotton emergence after flumioxazin PP treatment or the effects of rainfall after flumioxazin PDS application on cotton are unknown.

Flumioxazin acts by inhibiting protoporphyrinogen oxidase (protoporphyrin IX:oxygen oxidoreductase, EC 1.3.3.4) (Anonymous 1988, Cranmer et al. 2000). Inhibition of this enzyme induces accumulation of protoporphyrin IX due to uncontrolled autooxidation of the substrate (Duke et al. 1991). As protoporphyrin IX accumulates and is impinged by light, toxic oxygen radicals are generated which lead to degradation of plasmalemma and tonoplast membrane lipids and irreversible damage of their membrane function and structure in susceptible plants.

Localized injury has been observed on chlorophyllous green cotton stems less than 30 cm tall when flumioxazin was applied as a PDS (Altom et al. 2000). Severe injury may occur when flumioxazin contacts cotton foliage, as when heavy rain splashes treated soil onto leaves, or when the herbicide is misapplied (Wilcut et al. 2000). Previous research has shown that flumioxazin can be applied safely as a precise PDS to 15- to 30-cm tall cotton (Askew et al. 2002, Main et al. 2000). Less injury is observed on older cotton plants (approximately 12-leaf) where a layer of bark develops on the stem up to approximately 10 cm above the soil surface. This increased tolerance may be due to decreased flumioxazin absorption into the stem, increased translocation out of the stem, or increased metabolism by more mature plants. The presence of a bark layer composed of highly lignified cells may also minimize localized flumioxazin injury. However, no studies have been conducted to evaluate absorption, translocation, and metabolism of ^{14}C-flumioxazin as well as herbicidal damage to stem tissue in cotton as influenced by growth stage and harvest times to explain increased tolerance of mature cotton versus younger cotton to flumioxazin applied as a PDS.

Morningglory are annual low climbing vines that weight down stems and leaves of important crops as they exhibit positive phototropism to intercept sunlight. Morningglory reduce crop yields by competing for resources such as light, nutrients, and water (Cordes and Bauman 1984). Morningglory also reduce harvested crop quality, and in moderate populations, they can reduce harvesting efficiency (Buchanan et al. 1980; Cordes and Buchanan 1984; Howe et al. 1987; Murdock et al. 1986).

Morningglory can grow and reproduce readily on the ground surface, however, in the field, they appear to grow preferentially toward upright (erect) plants or structures. Location of neighboring plants or objects may be due to a phototropic response, a basic growth-orienting process in which unilateral light plays a central role in orienting shoots of plants to grow asymmetrically. Subsequently an asymmetric distribution of auxin on the shaded side leads to cell elongation and stem curvature toward the strongest sources of unilateral light (Kaufman et al. 1995). Proximity of neighboring green vegetation in which morningglory could climb may also be detected by the quality of light within the red and far-red wavelengths (600 to 800 nm). This response mechanism utilizes phytochromes that detect light quality, specifically, the balance between red and far-red light. Open canopies have a high red to far-red ratio. As a canopy closes due to increased plant height and width, the ratio of red to far-red becomes smaller descending toward the ground. In most plants, nearby vegetation would cause these result in the initiation of shade-avoidance reactions.

We are not aware of any published literature concerning responses of morningglory to neighboring plants and objects. Based on our observation in the field, we hypothesize that morningglory preferentially grow towards structure that reflect regions of more intense reflected solar radiation or altered light quality. Characterizing this response of morningglory to locate neighboring plants may suggest cultural farming practices or growth regulators that could be used to divert morningglory from growing towards crop plants.

Previous research has shown that peanut has the potential to injury peanut. Burke et al. (2003) reported 50 to 67% peaunt injury and reduced yield at one North Carolina location from flumioxazin containing treatments; however, injury was less than 2% at two other locations within the same study and yield was unaffected. Burke et al. hypothesized that injury reported in this study was likely increased by cool, wet conditions. In a second study in North Carolina, Scott et al (2001b) reported 10% peanut injury at one North Carolina location from flumioxazin-treatments; however, injury was not visibly apparent at a later rating. In a third study in North Carolina, Askew et al. (1999) reported peanut stunting of greater that 60% followed by as much as 35% discoloration consisting of necrotic spots on foliage. Askew et al. also hypothesized injury was caused by cold, wet conditions that existed during the 2 wk after flumioxazin application. Peanut stunting in Georgia ranging up to 16% was reported by Grichar and Colburn (1996) from flumioxazin plus trifluralin treatments. No peanut injury was noted 6 to 8 wk after treatment in this study. In a greenhouse study, Vencill (2002) found that peanut injury was related to peanut planting depth and flumioxazin placement depth. However, little data is presented in this paper to support the author's claims. Swann (2002) reported between 43 and 68% injury in studies conducted in 2000 and 2001 respectively. Injury declined to less than 9% in both studies and yield was unaffected compared to commonly used peanut treatments. Injury was reduced in these studies in plots where rainfall followed flumioxazin application and preceded crop emergence. However, no studies have been conducted to investigate the influence of temperature on flumioxazin treated peanut seed germination, as well as the influence of increasing simulated rainfall intervals between soil-applied flumioxazin PRE application and peanut emergence. Also, no studies have been conducted to evaluate the differential tolerances exhibited by peanut, morningglory, and sicklepod to flumioxazin applied PRE

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CHAPTER 2

Weed Management with Diclosulam in Peanut (*Arachis hypogaea*)

Abstract: Field experiments were conducted at three locations in North Carolina in 1998 and 1999 and one location in Virginia in 1998 to evaluate weed management systems in peanut. Treatments consisted of diclosulam alone preemergence (PRE) or diclosulam plus metolachlor PRE alone or followed by (fb) bentazon plus acifluorfen postemergence (POST). These systems were also compared with current commercial treatments of metolachlor PRE fb bentazon plus acifluorfen POST or imazapic POST. Data indicates that diclosulam PRE plus metolachlor PRE in conventional tillage peanut production usually controlled common lambsquarters, common ragweed, prickly sida, and entireleaf morningglory. However, control of spurred anoda, goosegrass, ivyleaf morningglory, large crabgrass, and pitted morningglory by this system was inconsistent and may require additional POST herbicide treatments. Systems that included diclosulam plus metolachlor PRE consistently provided high yields and net returns.

Nomenclature: Acifluorfen, bentazon, diclosulam, imazapic, metolachlor; common lambsquarters, *Chenopodium album* L. # CHEAL; common ragweed, *Ambrosia artemisiifolia* L. # AMBEL; entireleaf morningglory, *Ipomoea hederacea* var. *integruiscula* Grey # IPOHG; goosegrass, *Eleusine indica* (L.) Gaertn. # ELEIN; ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq # IPOHE; large crabgrass, *Digitaria sanguinalis* L. Scop. # DIGSA; pitted morningglory, *Ipomoea lacunosa* L. # IPOLA; prickly sida, *Sida spinosa* L. # SIDSP; spurred anoda, *Anoda cristata* L. #ANVCR; peanut, *Arachis hypogaea* L., NC 10C, NC 12C.

Additional index words: Economic analysis.

Introduction

Weed management in peanut traditionally requires soil-applied preplant incorporated (PPI) or PRE herbicides and generally at least one application of POST herbicide combinations (Bailey et al. 1999a; Bridges et al. 1994; Wilcut et al. 1994). Annual grasses, common lambsquarters, common ragweed, common cocklebur (*Xanthium strumarium* L.), *Ipomoea* species, *Amaranthus* species, and yellow nutsedge (*Cyperus esculentus* L.) are some of the most common weeds found in peanut production in the Southeast U.S. (Bridges et al. 1994). Control of this weed complex requires multiple herbicide treatments (Askew et al. 1999; Bailey et al. 1999a, 1999b; Wilcut and Swann 1990; Wilcut et al. 1991; York et al. 1995)

Soi-applied herbicides registered for application in Southeastern U.S. peanut production include diclosulam, dimethenamid, ethalfluralin, flumioxazin, imazethapyr, metolachlor, and pendimethalin. Ethalfluralin and pendimethalin PPI control annual grasses and small-seeded broadleaf weeds; however, they do not control large-seeded broadleaf weeds commonly found in Southeastern U.S. peanut fields including common ragweed, eclipta (*Eclipta prostrata* L.), annual *Ipomoea* species, and prickly sida (Askew et al. 1999; Bridges et al. 1994; Wilcut and Swann 1990; Wilcut et al. 1990, 1994). These weeds often require multiple applications of POST herbicides for season-long control (Bailey et al. 1999a, 1999b; Wilcut and Swann 1990). Imazethapyr soil-applied or POST does not control common ragweed or eclipta (Wilcut et al. 1991; York et al. 1995).

Approximately 70% of the North Carolina-Virginia peanut hectarage receives a soil treatment of metolachlor which controls annual grasses and provides partial control of common lambsquarters, *Amaranthus* species, and yellow nutsedge (Bridges et al. 1994;

Wilcut et al. 1994). A broad-spectrum soil-applied herbicide applied in conjunction with metolachlor would be beneficial in reducing the types and number of herbicides applied and the number of trips through the field (Bailey et al. 1999a, 1999b).

Diclosulam is a new triazolopyrimidine sulfonanilide soil-applied herbicide recently registered for PPI and PRE treatment in peanut (Anonymous 2000). Ethalfluralin PPI plus diclosulam PPI or PRE has shown activity on a broad spectrum of weeds including common lambsquarters, eclipta, entireleaf morningglory, pitted morningglory, and yellow nutsedge (Bailey et al. 1999a, 1999b, 2000; Baughman et al. 2000; Dotray et al. 2000; Main et al. 2000; Prostko et al. 1998). Peanut cultivars have shown excellent tolerance to diclosulam (Bailey et al. 2000; Main et al. 2000). Since metolachlor is the most commonly used soil-applied herbicide in peanut (Bridges et al. 1994), diclosulam needs to be evaluated in metolachlor-based systems. Therefore, studies were conducted to evaluate weed control, crop response, peanut yield, and economic returns from herbicide systems containing diclosulam plus metolachlor PRE.

Materials and Methods

Field experiments were conducted at the Upper Coastal Plain Research Station near Rocky Mount, NC, in 1998, the Peanut Belt Research Station located near Lewiston, NC, in 1998 and 1999, and the Tidewater Agricultural Research and Extension Center near Suffolk, VA, in 1998. Soils were a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudults) with 1.1% organic matter and pH 5.8 at Rocky Mount in 1998, 1.1% organic matter and pH 5.9 at Lewiston in 1998 and 1999, and 1.5% organic matter and pH 6.1 at Suffolk in 1998. These soil types are representative of the major peanut-producing areas of the U.S.

Virginia market-type peanut cultivars planted were NC 7 at Rocky Mount, NC 10C at Lewiston, and NC-V 11 at Suffolk. These three cultivars are among the most commonly grown in the North Carolina-Virginia region (Spears 2000). Peanuts were planted 5 cm deep in smooth seedbeds, at 120 to 130 kg/ha in 91 cm rows. Seeding rates were typical for Southeastern U.S. peanut and following Cooperative Extension Service recommendations (Jordan 2000). Pest management programs other than herbicide programs were based on Cooperative Extension Service recommendations (Bailey 2000; Brandenburg 2000).

Weed species evaluated included common lambsquarters, common ragweed, entireleaf morningglory, goosegrass, ivyleaf morningglory, large crabgrass, pitted morningglory, prickly sida, and spurred anoda. At the time of POST treatments, broadleaf weeds were between cotyledon and four-leaf growth stage; grasses were between cotyledon and three-tiller growth stage, and all weeds had varying densities (see table footnotes). POST treatments were applied approximately 3 wks after peanut emergence. This application timing is typical of commercial postemergence systems in peanut (Wilcut et al. 1994).

Soil applied herbicide treatments included diclosulam applied PRE at 17.5, 27, and 52 g ai/ha alone and in mixture with metolachlor PRE at 1.4 kg ai/ha. Additional diclosulam treatments included metolachlor PRE at 1.4 kg/ha plus diclosulam PRE at 17.5 or 27 g/ha fb acifluorfen at 0.28 g ai/ha plus bentazon at 0.56 kg ai/ha POST. Treatments of metolachlor PRE at 1.4 kg/ha fb acifluorfen at 0.28 g/ha plus bentazon at 0.56 kg/ha POST or metolachlor PRE at 1.4 kg/ha fb imazapic at 72 g ai/ha POST were included as representatives of current commercial weed control regimes. For comparison, a non-treated check was also included in the treatments. Nonionic surfactant at 0.25% (v/v) was included with all POST applications. Clethodim late POST at 0.14 kg ai/ha plus crop oil concentrate at 1% (v/v) was applied to all North Carolina plots except the untreated check to provide season-long control of annual grasses including broadleaf signalgrass (*Bracharia platyphylla* (Griseb.) Nash), goosegrass, large crabgrass, and Texas panicum (*Panicum texanum* Buckl.). This treatment was needed to facilitate harvest as the fiberous root systems of annual grasses interfere with digging and harvesting operations (Wilcut et al. 1994). The experimental design was a randomized complete block with three replications. Plot size was four 91 cm rows that were 6.1 m in length at all locations. The center two rows of each plot were harvested in mid-October of each year using conventional harvesting equipment.

Visual estimates of weed control were recorded early (mid-June) and late (late August) in the season just prior to harvest (Frans et al. 1986). Because weed control at the end of the season influenced peanut yield and harvest efficiency, only late season evaluations of weed control are presented (Wilcut et al. 1994). Peanut injury was evaluated 2 and 5 weeks after planting.

Net returns to land and management were determined by substituting the cost of each herbicide system for weed control and average yield into a North Carolina farm budget (Brown 1999). All costs, with the exception of those used for weed control, were based on this budget generator. The production costs included cultural and pest management procedures, equipment and labor, interest on operating equipment, harvest operations including drying and hauling, and general overhead costs. Quotes of herbicide and adjuvant costs were obtained from two North Carolina agricultural suppliers and averaged. Costs of herbicide application were $4.28/ha per application, based on estimates developed by the Department of Agriculture and Resource Economics at North Carolina State University. Herbicide system costs represent the sum of all application, herbicide, and adjuvant costs. Net returns were calculated by multiplying yield/ha by 100% of the price support ($0.67/kg) and subtracting total production costs for each treatment.

Data were tested for homogeneity of variance by plotting residuals. An arcsin square-root transformation did not improve variance homogeneity, thus non-transformed data were used in the analysis and presentation for clarity. Data from the non-treated control was deleted prior to analysis to stabilize variance since visually estimated weed control ratings were set to zero and peanut yield could not be harvested due to weed biomass interference with machinery. Analysis of variance was conducted using the general linear models procedure in SAS (SAS 1998) to evaluate the effect of the various herbicide treatments on crop injury, weed control, and crop yield. Sums of squares were partitioned to evaluate location and year effects that were considered a single random variable. Main effects and interactions were tested by the appropriate mean square associated with the random variable (McIntosh 1983). Mean separations were performed using Fisher's protected LSD test at P=0.05.

Results and Discussion

Peanut injury. Because injury was 2% or less at the first evaluation with no differences between soil-applied treatments and injury was 10% or less at the second evaluation and was typical for POST herbicide treatment crop injury (Prostko and Baughman 1999), no injury data will be discussed (data not shown).

Weed control. *Common lambsquarters*. There was a location by treatment interaction, thus data are presented by location. At three of four locations, diclosulam PRE at all rates provided at least 90% control of common lambsquarters with no differences in control with higher rates of diclosulam treatments (Table 1). Common lambsquarters in Virginia was controlled by diclosulam PRE 62 to 73% with no differences among treatments. The addition of metolachlor to the two higher rates of diclosulam PRE improved control at least 12 percentage points at the Virginia location. Because common lambsquarters at all North Carolina locations was controlled with diclosulam PRE treatments, control was not further improved with addition of metolachlor or POST herbicides. Metolachlor plus diclosulam PRE fb acifluorfen plus bentazon POST provided common lambsquarters control of 97 to 100%, depending on location, while metolachlor PRE fb imazapic POST provided common lambsquarters control ranging from 79 to 98%, depending on location. Metolachlor PRE fb acifluorfen plus bentazon POST controlled common lambsquarters a minimum of 92% at all locations. Thus, metolachlor fb imazapic POST was less effective for consistent common lambsquarters control compared to diclosulam PRE plus POST systems or acifluorfen plus bentazon POST systems.

Common ragweed. There was a location by treatment interaction, thus data are presented by location. All herbicide systems controlled common ragweed 100% at Rocky Mount and Virginia locations in 1998 (Table 1). However, in Lewiston in 1999, >80% control required diclosulam PRE at 52 g/ha alone or any rate of diclosulam plus metolachlor PRE with or without POST herbicides. Because of the excellent control provided by diclosulam PRE in North Carolina, the addition of POST herbicides was not beneficial.

Metolachlor PRE fb acifluorfen plus bentazon POST provided 100% common ragweed control in Virginia and Rocky Mount locations; however, control in Lewiston was 27%. Metolachlor PRE fb imazapic POST provided common ragweed control of ≥97% in Virginia and Rocky Mount locations while providing 66% control in Lewiston.

Prickly sida. There was a location by treatment interaction, thus data are presented by location. Diclosulam PRE at 17.5 g/ha provided prickly sida control of 63% and 100% in North Carolina and Virginia, respectively (Table 2). Control at Lewiston was increased to 74 and 97% as the diclosulam rate increased to 27 g/ha and 52 g/ha, respectively. Metolachlor plus diclosulam PRE at any rate provided prickly sida control of at least 95% at both locations and control was not further increased with POST herbicides. Weed management systems that used metolachlor PRE fb acifluorfen plus bentazon POST or imazapic POST controlled at least 95% of the prickly sida population.

Spurred anoda. There was a location by treatment interaction, thus data are presented by location. Spurred anoda control with diclosulam PRE was inconsistent (Table 2). Diclosulam PRE at all rates controlled spurred anoda 71% or less at Lewiston in 1998 but controlled 100% of the population in Virginia. The addition of metolachlor to diclosulam PRE at the two lower diclosulam rates improved spurred anoda control in North Carolina to ≥70%. Metolachlor plus diclosulam PRE fb POST herbicides controlled spurred anoda ≥88% in Lewiston while metolachlor PRE fb imazapic POST controlled 100% of the spurred anoda population.

Entireleaf morningglory. There was a location by treatment interaction, thus data are presented by location. At Rocky Mount in 1998 all systems controlled ivyleaf morningglory at least 97% and differences among treatments are unlikely to be of agronomic importance (Table 2). At Lewiston in 1999, diclosulam PRE at the two higher rates provided 70 to 95% control of entireleaf morningglory. Addition inputs of other herbicides did not improve control. Metolachlor PRE fb acifluorfen plus bentazon POST was less effective than diclosulam PRE containing systems while metolachlor PRE fb imazapic POST provided control comparable to the better diclosulam systems.

Ivyleaf and pitted morningglory. There was a location by treatment interaction, thus these data are presented by location. Ivyleaf and pitted morningglory control with diclosulam PRE alone or in combination with metolachlor was inconsistent (Tables 2 and 3). Diclosulam PRE at all rates alone or with metolachlor provided less than 80% control of ivyleaf or pitted morningglory at the three North Carolina locations. However diclosulam provided greater than 90% control at the Virginia location. The addition of metolachlor to diclosulam PRE did not increase control for either morningglory species at any location. Metolachlor plus diclosulam PRE at 17.5 g/ha fb acifluorfen plus bentazon POST provided 93% or greater control at all locations except at Lewiston in 1999 where control was 77%. Control was independent of diclosulam rate. Metolachlor PRE fb acifluorfen plus bentazon POST provided 63 to 87% control depending on location. This control was less than the systems that included diclosulam except at Lewiston in 1999 where control was equivalent. Metolachlor PRE fb imazapic POST controlled ivyleaf and pitted morningglory 85 to 95%. The most consistent control of both ivyleaf and pitted morningglory was obtained with metolachlor plus diclosulam PRE at 27 g/ha fb acifluorfen plus bentazon POST.

Goosegrass. There was a location by treatment interaction, thus data are presented by location. Diclosulam PRE at 17.5 g/ha controlled goosegrass 53 to 82% in Virginia with the highest level of control obtained with the 52 g/ha rate of diclosulam (Table 3). All metolachlor systems controlled goosegrass 100% in Virginia. The level of goosegrass control provided by all systems was not adequate in North Carolina and all plots received a late POST treatment of clethodim, which resulted in at least 97% control of goosegrass.

Large crabgrass. There was a location by treatment interaction, thus data are presented by location. Diclosulam PRE at all three rates controlled large crabgrass 95% in Virginia (Table 3). The level of large crabgrass control provided by all systems was not adequate in North Carolina and the reported 99% control is again attributed to the late POST treatment of clethodim to all North Carolina plots.

Peanut Yield. There was a location by treatment interaction for peanut yield, thus data are presented by location. Peanut treated with diclosulam PRE at any rate yielded similarly at each location (3,500 to 5,520 kg/ha) except at Lewiston in 1999 where the highest rate (52g/ha) provided higher yields when compared to the 27 g/ha rate (Table 4). The addition of metolachlor to diclosulam PRE at all rates increased yields in six of twelve comparisons. The addition of POST herbicides to metolachlor plus diclosulam PRE systems increased yields in only one of eight comparisons. Metolachlor PRE fb acifluorfen plus bentazon POST provided yields equivalent to those containing diclosulam PRE plus metolachlor PRE fb acifluorfen plus bentazon POST in seven of eight comparisons. Metolachlor PRE fb imazapic POST provided yields equivalent to the highest yielding diclosulam systems.

Economic Return. Net returns from each herbicide system followed the same general trend as peanut yield (Table 5). Peanut treated with diclosulam PRE at any rate provided similar returns (761 to 2204 $/ha) at each location. The addition of metolachlor PRE to diclosulam PRE at all rates increased returns in three of twelve comparisons with diclosulam PRE alone. The addition of POST herbicides to metolachlor plus diclosulam PRE systems increased returns in three of eight comparisons. Metolachlor PRE fb acifluorfen plus bentazon POST provided returns equivalent to those containing diclosulam PRE plus metolachlor PRE fb acifluorfen plus bentazon POST in seven of eight comparisons. Metolachlor PRE fb imazapic POST provided net returns equivalent to the highest net returns from diclosulam systems.

POST herbicides used in this study did not always increase weed control for diclosulam plus metolachlor PRE systems. The addition of metolachlor to diclosulam PRE increased weed control for some weed species. Our data indicates that diclosulam PRE plus metolachlor PRE in conventional tillage peanut production usually controlled common lambsquarters, common ragweed, prickly sida, and entireleaf morningglory. However, control of spurred anoda, ivyleaf morningglory, and pitted morningglory by this system was inconsistent and may require additional POST herbicide treatments. Peanut yields and net returns were reflective of levels of weed management. Systems that included diclosulam PRE plus metolachlor PRE consistently provided high yields and net returns.

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Table 1. Influence of herbicide systems on common lambsquarters and common ragweed control at one Virginia and three North Carolina locations in 1998 and 1999.

	Common lambsquarters[c]				Common ragweed		
	Rocky Mt.	Lewiston	Virginia	Lewiston	Rocky Mt.	Virginia	Lewiston
Herbicide system	1998	1998	1998	1999	1998	1998	1999
	% control						
Diclosulam 17.5 g ai/ha	90ab[d]	98a	62e	92a	100a	100a	58d
Diclosulam 27 g/ha	95ab	100a	62e	100a	100a	100a	76bcd
Diclosulam 52 g/ha	97a	98a	73de	100a	100a	100a	93a
Diclosulam 17.5 g/ha + metolachlor[a]	92ab	96a	72de	100a	100a	100a	88ab
Diclosulam 27 g/ha + metolachlor	93ab	97a	85c	100a	100a	100a	95a
Diclosulam 52 g/ha + metolachlor	96ab	100a	90c	100a	100a	100a	85abc
Diclosulam 17.5 g/ha + metolachlor fb acifluorfen plus bentazon[b]	97a	100a	100a	100a	100a	100a	91ab

Table 1. continued

Diclosulam 27 g/ha + metolachlor fb acifluorfen plus bentazon	99a	100a	100a	100a	100a	100a	97a
Metolachlor fb acifluorfen + bentazon	92ab	100a	97b	100a	100a	100a	27e
Metolachlor fb imazapic	79b	98a	82cd	96a	100a	97b	66cd

[a] Metolachlor PRE was applied at 1.4 kg/ha.

[b] Rates of POST herbicides were: acifluorfen and bentazon were applied at 0.28 kg/ha and 0.56 kg/ha, respectively. Imazapic was applied at 0.071 kg/ha. Clethodim was applied late postemergence at 0.14 kg ai/ha on all plots except the untreated checks.

[c] Weed densities: common lambsquarters (1-12/m^2), common ragweed (1-16/m^2). All weeds had between cotyledon and 4 true leaves.

[d] Mean separations followed by the same letter are not significantly different. Mean separations were performed using Fisher's protected LSD test at P=0.05.

Table 2. Influence of herbicide systems on prickly sida, spurred anoda, entireleaf morningglory, and ivyleaf morningglory control at one Virginia and three North Carolina locations in 1998 and 1999.

	Prickly sida[c]		Spurred anoda		Entireleaf morningglory		Ivyleaf morningglory	
	Lewiston	Virginia	Lewiston	Virginia	Rocky Mt.	Lewiston	Lewiston	Virginia
Herbicide system	1998	1998	1998	1998	1998	1999	1998	1998
	% control							
Diclosulam 17.5 g ai/ha	63b[d]	100a	26f	100a	100a	70de	12f	90bc
Diclosulam 27 g/ha	74b	100a	43ef	100a	100a	95ab	37d	92abc
Diclosulam 52 g/ha	97a	100a	71cd	100a	100a	90abc	67c	100a
Diclosulam 17.5 g/ha + metolachlor[a]	95a	100a	70cd	100a	97b	85bcd	18ef	87c
Diclosulam 27 g/ha + metolachlor	97a	100a	81bc	100a	100a	98ab	30de	97ab
Diclosulam 52 g/ha + metolachlor	97a	100a	58de	100a	100a	100a	43d	97ab
Diclosulam 17.5 g/ha + metolachlor fb acifluorfen plus bentazon[b]	100a	100a	93ab	100a	100a	80cde	93a	97ab

<u>Table 2</u>. continued

Diclosulam 27 g/ha + metolachlor fb acifluorfen plus bentazon	100a	100a	88b	100a	100a	97ab	94a	100a
Metolachlor fb acifluorfen + bentazon	100a	95b	52de	100a	100a	62e	81bc	85c
Metolachlor fb imazapic	100a	100a	100a	100a	100a	93ab	92ab	85c

[a] Metolachlor PRE was applied at 1.4 kg/ha.

[b] Rates of POST herbicides were: acifluorfen and bentazon were applied at 0.28 kg/ha and 0.56 kg/ha, respectively. Imazapic was applied at 0.071 kg/ha. Clethodim was applied late postemergence at 0.14 kg ai/ha on all plots except the untreated checks.

[c] Weed densities: prickly sida (1-12/m^2), spurred anoda (1-5/m^2), entireleaf morningglory (1-15/m^2), ivyleaf morningglory (1-25/m^2). All weeds had between cotyledon and 4 true leaves.

[d] Mean separations followed by the same letter are not significantly different. Mean separations were performed using Fisher's protected LSD test at P=0.05.

Table 3. Influence of herbicide systems on pitted morningglory, goosegrass and large crabgrass control at one Virginia and three North Carolina locations in 1998 and 1999.

	Pitted morningglory[c]			Goosegrass[d]			Large crabgrass	
	Lewiston	Virginia	Lewiston	Rocky Mt.	Virginia	Lewiston	Virginia	Lewiston
Herbicide system	1998	1998	1999	1998	1998	1998	1998	1999
	% control							
Diclosulam 17.5 g ai/ha	14f[e]	92bcd	55c	97cd	53c	98b	95b	100a
Diclosulam 27 g/ha	35de	95abc	82ab	97cd	65c	99ab	95b	100a
Diclosulam 52 g/ha	67c	100a	80ab	99abc	82b	100a	100a	99b
Diclosulam 17.5 g/ha + metolachlor[a]	19ef	90bcd	79abc	97cd	100a	100a	100a	100a
Diclosulam 27 g/ha + metolachlor	28def	98ab	94a	100a	100a	100a	100a	100a
Diclosulam 52 g/ha + metolachlor	42d	98ab	89ab	99ab	100a	100a	100a	100a
Diclosulam 17.5 g/ha + metolachlor fb acifluorfen plus bentazon[b]	96a	97ab	77abc	98bc	100a	100a	100a	100a

Table 3. continued

Diclosulam 27 g/ha + metolachlor fb acifluorfen plus bentazon	95a	100a	82abc	99ab	100a	100a	100a	100a
Metolachlor fb acifluorfen + bentazon	83bc	87cd	63bc	93c	100a	100a	100a	100a
Metolachlor fb imazapic	95ab	87d	91a	100a	100a	100a	100a	100a

[a] Metolachlor PRE was applied at 1.4 kg/ha.

[b] Rates of POST herbicides were: acifluorfen and bentazon were applied at 0.28 kg/ha and 0.56 kg/ha, respectively. Imazapic was applied at 0.071 kg/ha. Clethodim was applied late postemergence at 0.14 kg ai/ha on all plots except the untreated checks.

[c] Weed densities: pitted morningglory (20-35/m^2), goosegrass (1-20/m^2), large crabgrass (20-35/m^2). Pitted morningglory had between cotyledon and 4 true leaves. Goosegrass and large crabgrass were between cotyledon and three-tiller growth stage.

[d] The level of goosegrass and large crabgrass control provided by all systems was not adequate in North Carolina and the reported control is attributed to the late POST treatment of clethodim to all North Carolina plots.

[e] Mean separations followed by the same letter are not significantly different. Mean separations were performed using Fisher's protected LSD test at P=0.05.

Table 4. Influence of herbicide systems on peanut yield at one Virginia and three North Carolina locations in 1998 and 1999.

	Yield							
	Rocky Mt.		Lewiston		Virginia		Lewiston	
Herbicide system	1998		1998		1998		1999	
	Kg/ha							
Diclosulam 17.5 g ai/ha	5040	b[c]	3350	ab	4140	abc	3890	cd
Diclosulam 27 g/ha	5520	ab	3660	ab	3500	c	3860	d
Diclosulam 52 g/ha	4990	b	3430	ab	3960	bc	4400	abc
Diclosulam 17.5 g/ha + metolachlor[a]	5620	ab	3220	b	5180	a	4610	a
Diclosulam 27 g/ha + metolachlor	5640	ab	3730	ab	5070	ab	4530	a
Diclosulam 52 g/ha + metolachlor	5730	a	4030	a	5160	a	4390	abcd
Diclosulam 17.5 g/ha + metolachlor fb acifluorfen plus bentazon[b]	5900	a	4100	a	5140	a	4510	a
Diclosulam 27 g/ha + metolachlor fb acifluorfen plus bentazon	5230	ab	3830	ab	5060	ab	4440	ab
Metolachlor fb acifluorfen + bentazon	5450	ab	3800	ab	4260	abc	3930	bcd
Metolachlor fb imazapic	5370	ab	3860	ab	4070	abc	4400	abc

[a] Metolachlor PRE was applied at 1.4 kg/ha.

[b] Rates of POST herbicides were: acifluorfen and bentazon were applied at 0.28 kg/ha and 0.56 kg/ha, respectively. Imazapic was applied at 0.071 kg/ha. Clethodim was applied late postemergence at 0.14 kg ai/ha on all plots except the untreated checks.

[c] Mean separations followed by the same letter are not significantly different. Mean separations were performed using Fisher's protected LSD test at $P=0.05$.

Table 5. Interaction of herbicide systems on herbicide application cost and economic net returns at one Virginia and three North Carolina locations in 1998 and 1999.

		Economic net returns							
	Herbicide	Rocky Mt.		Lewiston		Virginia		Lewiston	
Herbicide system	cost[d]	1998		1998		1998		1999	
		$/ha							
Diclosulam 17.5 g ai/ha	19.06	1893	b[c]	761	b	1285	ab	1122	b
Diclosulam 27 g/ha	26.28	2204	ab	958	b	849	b	1094	b
Diclosulam 52 g/ha	46.65	1829	b	781	b	1130	ab	1438	ab
Diclosulam 17.5 g/ha + metolachlor[a]	45.33	2262	ab	648	b	1966	a	1580	a
Diclosulam 27 g/ha + metolachlor	52.55	2264	ab	982	ab	1882	a	1518	a
Diclosulam 52 g/ha + metolachlor	72.92	2307	ab	1166	ab	1922	a	1407	ab
Diclosulam 17.5 g/ha + metolachlor fb acifluorfen plus bentazon[b]	80.83	2407	a	1202	a	1900	a	1475	ab
Diclosulam 27 g/ha + metolachlor fb acifluorfen plus bentazon	88.05	1953	b	1013	ab	1837	a	1422	ab
Metolachlor fb acifluorfen + bentazon	61.77	2125	ab	1016	ab	1331	ab	1107	b
Metolachlor fb imazapic	92.82	2040	ab	1031	ab	1171	ab	1392	ab

[a] Metolachlor PRE was applied at 1.4 kg/ha.

Table 5. continued

[b] Rates of POST herbicides were: acifluorfen and bentazon were applied at 0.28 kg/ha and 0.56 kg/ha, respectively. Imazapic was applied at 0.071 kg/ha. Clethodim was applied late postemergence at 0.14 kg ai/ha on all plots except the untreated checks.

[c] Mean separations followed by the same letter are not significantly different. Mean separations were performed using Fisher's protected LSD test at P=0.05.

[d] Herbicide costs were calculated by summing application, herbicide cost, and adjuvant cost.

CHAPTER 3

Weed Management with Diclosulam in Strip-Tillage Peanut (*Arachis hypogaea*)

Abstract: Experiments were conducted at three locations in NC in 1999 and 2000 to evaluate weed management systems in strip-tillage peanut. Diclosulam was evaluated with standard preemergence (PRE), early postemergence (EPOST), and postemergence (POST) herbicide systems in a factorial treatment arrangement. Preemergence treatments that contained diclosulam controlled common lambsquarters, common ragweed, and eclipta 100%. Diclosulam PRE controlled entireleaf morningglory 88%, ivyleaf morningglory ≥90%, pitted morningglory ≥81%, and prickly sida ≥94%. Yellow nutsedge control with diclosulam ranged from 65 to 100% depending on location while POST systems containing imazapic controlled yellow nutsedge at least 89%, regardless of PRE herbicides. Peanut yields and net returns reflectived levels of weed management. Systems that included diclosulam PRE plus POST herbicides consistently provided high yields and net returns. Clethodim late POST was required for full season control of annual grasses including broadleaf signalgrass, goosegrass, large crabgrass, and Texas panicum.

Nomenclature: Clethodim, diclosulam, imazapic, broadleaf signalgrass, *Brachiaria platyphylla* (Griseb.) Nash # BRAPP; common lambsquarters, *Chenopodium album* L. # CHEAL; common ragweed, *Ambrosia artemisiifolia* L. # AMBEL; eclipta, *Eclipta prostrata* L. # ECLAL; entireleaf morningglory, *Ipomoea hederacea* var. *integriuscula* Gray # IPOHG; goosegrass, *Eleusine indica* (L.) Gaertn. # ELEIN; ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq. # IPOHE; large crabgrass, *Digitaria sanguinalis* (L.) Scop. # DIGSA; pitted morningglory, *Ipomoea lacunosa* L. # IPOLA; prickly sida, Sida spinosa L. #SIDSP, Texas

panicum, *Panicum texanum* Buckl. # PANTE; yellow nutsedge, *Cyperus esculentus* L. # CYPES; peanut, *Arachis hypogaea* L., ‘NC 10C’ and ‘NC 12C’.

Additional index words: Economic analysis.

Abbreviations: EPOST, early postemergence; PRE, preemergence; POST, postemergence.

Introduction

Peanut has typically been grown in ridged conventional-tillage seedbeds (Sholar et al. 1995; Wilcut et al. 1987, 1990, 1994, 1995) which receive soil-applied preplant incorporated (PPI) and/or PRE herbicide treatments followed by (fb) multiple applications of EPOST and POST herbicide combinations (Wilcut et al. 1994). Concerns about declining soil organic matter, soil structure degeneration, increased subsoil compaction, and crop damage due to water stress and sandblasting have caused growers to devise ways to reduce tillage operations (Troeh et al. 1991). Strip tillage is a type of conservation tillage where the area within the crop row is tilled while the inter-row areas are not disturbed. This practice reduces soil erosion and evaporative water loss by leaving ≥ 30% crop residues on the soil surface, decreasing soil compaction, and increasing water infiltration (Troeh et al. 1991).

In peanut, herbicide systems are usually more intensive in strip-tillage when compared to conventional tillage because PRE or PPI within-the-row treatments provide reduced efficacy compared to conventional PPI treatments (Wilcut et al. 1987). Adequate weed control in minimum tillage requires PRE, EPOST, and POST herbicides (Wilcut et al. 1990). Depending on herbicide system, conventional-tillage peanut produced yields 800 to 1900 kg/ha higher than minimum tillage peanut, and also provided greater net returns (Wilcut et al. 1990). This may be due in part to more effective digging of peanut in conventional systems that are ridged compared to non-ridged minimum tillage peanut production (Grichar and

Boswell 1987). Since the late 1980's, registrations for dinoseb and naptalam in peanut either have been canceled or withdrawn. Additionally, concerns about alachlor-treated peanut have eliminated this herbicide from use in U. S. peanut production (Bridges et al. 1994; Wilcut et al. 1994, 1995). Herbicide registrations in peanut since 1990 include clethodim, diclosulam, dimethenamid, flumioxazin, imazapic, and pyridate. Thus, the herbicide options available for weed management in strip-tillage peanut production have changed appreciably since the late 1980's.

Soil-applied herbicides registered for use in peanut production include dimethenamid, ethalfluralin, imazethapyr, *s*-metolachlor, norflurazon, and pendimethalin. Pendimethalin and ethalfluralin applied PPI and *s*-metolachlor PPI or PRE control annual grasses and small-seeded broadleaf weeds (Wilcut et al. 1994). However, they do not control broadleaf weeds that are commonly found in North Carolina and Virginia peanut fields including common ragweed, eclipta, *Ipomoea* species, and prickly sida (Askew et al. 1999; Bridges et al. 1994; Wilcut and Swann 1990; Wilcut et al. 1990, 1994). These weeds often require multiple applications of POST herbicides for season-long control (Bailey et al. 1999a, 1999b; Wilcut and Swann 1990). Imazethapyr soil-applied does not control common ragweed or eclipta (Wilcut et al. 1991; York et al. 1995). Norflurazon is not used in North Carolina and Virginia peanut production because of crop tolerance concerns and potential for carryover to small grains, corn (*Zea mays* L.), and tobacco (*Nicotiana tobaccum* L.) (Anonymous 2000a; Jordan et al. 1998). A broad-spectrum soil-applied herbicide providing residual control could reduce inputs by reducing the types and number of herbicides applied and the number of trips through the field (Bailey et al. 1999a, 1999b).

Diclosulam is a triazolopyrimidine sulfonanilide soil-applied herbicide recently registered for PPI and PRE treatment in peanut (Anonymous 2000b). Ethalfluralin PPI plus diclosulam PPI or PRE controls a broad spectrum of annual broadleaf weeds and usually exhibits excellent crop tolerance in conventional tillage peanut (Bailey et al. 1999a, 1999b, 2000; Baughman et al. 2000; Dotray et al. 2000; Main et al. 2000; Prostko et al. 1998). The recent increase in reduced-tillage peanut production in the mid-Atlantic and Southeastern Coastal Plain and the paucity of data concerning diclosulam performance in reduced-tillage systems necessitates additional research. Therefore, studies were conducted to evaluate weed control, crop response, peanut yield, and economic returns from herbicides systems containing diclosulam in reduced-tillage peanut production.

Materials and Methods

Field experiments were conducted in one field at the Peanut Belt Research Station located near Lewiston, NC in 1999 and in two separate fields at the same location in 2000 to evaluate weed management systems in strip-tillage peanut. Soils in all fields consisted of a Norfolk loamy sand (fine-loamy, siliceous, Thermic Typic Paleudults) with between 1 to 1.1% organic matter and pH 5.5 to 6.0. Peanut cultivars included 'NC 10C' in 1999 and 'NC 12C' in 2000. Peanut was planted 5 cm deep at 120 to 130 kg/ha in 91-cm rows into corn stubble in 1999 and into cotton (*Gossypium hirsutum* L.) and soybean [*Glycine max* (L.) Merr.] stubble in 2000 (Jordan 2000). Pest management programs other than herbicide programs were based on North Carolina Cooperative Extension Service recommendations (Bailey 2000; Brandenburg 2000).

Common lambsquarters, common ragweed, eclipta, entireleaf morningglory, ivyleaf morningglory, pitted morningglory, prickly sida, and yellow nutsedge were each evaluated at two or three sites. At the time of EPOST and POST applications, broadleaf weeds were in the one- to seven-leaf-stage, yellow nutsedge was 15 to 25 cm tall and weed densities ranged from 3 to 10 plants per m^2 depending on species. Early postemergence treatments were applied 7 to 10 d after peanut emergence and POST treatments were applied approximately 2 wk after EPOST treatments. Paraquat at 0.7 kg ai/ha was applied to all plots three wk before planting to control existing vegetation. The PRE herbicide options included: 1) paraquat at 0.7 kg/ha plus dimethenamid at 1.4 kg ai/ha, 2) paraquat at 0.7 kg/ha plus diclosulam at 0.027 kg ai/ha, or 3) paraquat at 0.7 kg/ha plus dimethenamid at 1.4 kg/ha plus diclosulam at 0.027 kg/ha. Postemergence herbicides included 1) untreated, 2) paraquat at 0.14 kg ai/ha plus bentazon at 0.28 kg ai/ha EPOST followed by (fb) acifluorfen at 0.28 kg ai/ha plus bentazon at 0.56 kg ai/ha; or 3) paraquat at 0.14 kg/ha plus bentazon at 0.28 kg/ha EPOST fb imazapic at 0.07 kg ai/ha POST. A nonionic surfactant at 0.25% (v/v) was included in all EPOST and POST herbicide treatments. The paraquat burndown treatment served as the comparison for visual evaluations of weed control and crop injury. Clethodim late POST at 0.14 kg ai/ha plus crop oil concentrate at 1% (v/v) was applied to all plots except the untreated checks to provide season-long control of annual grasses including broadleaf signalgrass, goosegrass, large crabgrass, and Texas panicum. This treatment was needed to facilitate harvest as the fiberous root systems of annual grasses interfere with digging and harvesting operations (Wilcut et al. 1994). The experimental design was a randomized complete block with three replications. Plots were four rows 91 cm wide and 6.1 m long.

Visual estimates of weed control were recorded early (mid-June) and late in the season (late August) just prior to harvest. Weed control and peanut injury, based on leaf discoloration and biomass reduction as compared to the non-treated control, was visually estimated on a scale of 0 (no injury symptoms) to 100 (complete death of all plants or no plants present) (Frans et al. 1986). Since weed control at the end of the season influenced peanut yield and influenced harvest efficiency, only late season evaluations of weed control are presented (Wilcut et al. 1994). Peanut injury in the form of discoloration, stunting, and stand reduction was evaluated 2 and 5 wks after planting. The center two rows of each plot were harvested in mid-October of each year using conventional harvesting equipment.

Net returns to land and management were determined by substituting the cost of each herbicide system for weed control and average yield into a North Carolina farm budget (Brown 2000). All costs with the exception of those used for weed control were based on this budget generator. The production costs included cultural and pest management procedures, equipment and labor, interest on operating equipment, harvest operations including drying and hauling, and general overhead costs. Quotes of herbicide and adjuvant costs were obtained from two North Carolina agricultural suppliers and averaged. Cost of herbicide application was $4.28/ha, based on estimates developed by the Department of Agriculture and Resource Economics at North Carolina State University. Herbicide system costs represent the sum of all application, herbicide, and adjuvant costs. Net returns were calculated by multiplying yield per ha by the price support ($0.67/kg) and subtracting total production costs for each system.

Data from the control were deleted prior to analysis to stabilize variance since visually estimated weed control ratings were set to zero and peanut yield could not be harvested due to weed biomass interference with machinery. To recognize structure in the treatment arrangement, analysis of variance was conducted using the general linear models procedure in SAS (SAS 1998) to evaluate the effect of various PRE herbicide treatment options (three levels) and POST herbicide treatment options (three levels) on crop injury, weed control, and crop yield. Sums of squares were partitioned to evaluate location and year effects which were considered a single random variable. Main effects and interactions were tested by the appropriate mean square associated with the random variable (McIntosh 1983). Mean separations were performed using Fisher's protected LSD test at P=0.05.

Results and Discussion

Peanut injury. Injury was 2% or less at the first evaluation with no differences between soil applied treatments (data not shown) and was also typical for POST herbicide crop injury (5% or less at 5 WAT) (data not shown).

Weed control. *Yellow nutsedge*. ANOVA showed location interactions were significant; therefore, each location is discussed separately. Dimethenamid PRE alone controlled yellow nutsedge 32 to 64% depending on location (Table 1). The addition of bentazon plus paraquat EPOST fb acifluorfen plus bentazon POST to dimethenamid PRE provided control of 55 to 97 % depending on location. Diclosulam PRE alone or diclosulam plus dimethenamid PRE controlled yellow nutsedge 65 to 100% depending on location. Similar levels of yellow nutsedge control with *s*-metolachlor plus diclosulam PRE were shown in conventional-tillage peanut in Texas (Baughman et al. 2000). The addition of bentazon plus paraquat EPOST fb acifluorfen plus bentazon POST to diclosulam PRE or diclosulam plus dimethenamid PRE did not always increase control. Imazapic POST systems controlled yellow nutsedge ≥ 89%. This data is in agreement with earlier research and illustrates that imazapic is the POST standard for control of perennial sedges in peanut (Richburg et al. 1993, 1994).

Common ragweed. Since ANOVA showed no herbicide by location interactions for common ragweed, the data were combined over location. Dimethenamid PRE controlled common ragweed 82% while diclosulam PRE or dimethenamid plus diclosulam PRE controlled common ragweed ≥ 99% (Table 1). Acifluorfen, bentazon, and paraquat control small common ragweed but do not provide residual control (Wilcut and Swann 1990). Common ragweed control with dimethenamid plus EPOST and POST herbicides was at least 98%. Common ragweed infests 75% of North Carolina and Virginia peanut hectarage (Bridges et al. 1994).

Eclipta. As with common ragweed, ANOVA showed no treatment by location interactions for eclipta control, and data were combined over location. All treatments that included diclosulam controlled eclipta 100% (Table 1). Prostko et al. (1998) reported a minimum of 95% eclipta control with diclosulam PRE in conventional-tillage peanut. Dimethenamid PRE alone controlled eclipta 31%. The addition of bentazon plus paraquat EPOST fb acifluorfen plus bentazon POST to dimethenamid increased control by 47 percentage points over dimethenamid alone. Any POST systems containing imazapic controlled eclipta 100%. There are no other registered soil-applied herbicides in peanut that control eclipta (Wilcut et al. 1991, 1994, 1995).

Prickly sida. As with common ragweed and eclipta, ANOVA showed no treatment by location interactions for prickly sida control, and data were combined over location. Dimethenamid PRE did not control prickly sida (Table 1). Dimethenamid PRE fb paraquat plus bentazon EPOST fb acifluorfen plus bentazon POST controlled prickly sida 87% while imazapic POST systems controlled prickly sida 100%. Diclosulam PRE and diclosulam plus dimethenamid PRE controlled prickly sida 94% and 97% respectively. The addition of EPOST plus POST herbicides to dimethenamid plus diclosulam increased control to 100%.

Similar results with diclosulam PPI or PRE fb POST herbicides have been reported in conventional-tillage peanut (Bailey et al. 1999a, 1999b).

Entireleaf and pitted morningglory. Since ANOVA showed no herbicide by location interactions for entireleaf and pitted morningglory, data were combined over location. Dimethenamid PRE did not control entireleaf morningglory or pitted morningglory (Table 2). The acifluorfen plus bentazon POST system controlled entireleaf and pitted morningglory ≥85% while the imazapic POST system controlled 100% of these populations. Similar control levels were reported with imazapic (AC 263,622) in Georgia (Richburg et al. 1995, 1996). Diclosulam PRE with or without dimethenamid controlled entireleaf and pitted morningglory at least 81% which is similar to control levels reported in Texas (Dotray et al. 2000). Control ≥ 93% was observed with the additional inputs of EPOST and POST herbicides to dimethenamid systems. Scott et al. (2001) saw similar results with diclosulam PRE in conventional-tillage peanut.

Ivyleaf morningglory. ANOVA showed location interactions were significant; therefore, each location is discussed separately. As seen with entireleaf and pitted morningglory, dimethenamid PRE did not control ivyleaf morningglory at either location (Table 2). At Lewiston A, control was 87% with EPOST herbicides fb acifluorfen plus bentazon POST to dimethenamid while imazapic POST systems controlled 100%. Diclosulam PRE with or without dimethenamid PRE controlled entireleaf morningglory ≥94%. At Lewiston B, control was 94% with EPOST herbicides fb acifluorfen plus bentazon POST to dimethenamid while imazapic POST systems controlled 100%. Diclosulam PRE with or without dimethenamid PRE controlled entireleaf morningglory ≥90%. Because the level of control with diclosulam was high, control was not increased when diclosulam was fb EPOST plus POST herbicide treatments. Annual *Ipomoea* species infest at least 80% of the peanut hectares in North Carolina and Virginia (Bridges et al. 1994).

Peanut Yield. ANOVA showed location interactions were significant; therefore, each location is discussed separately. Peanut treated with dimethenamid PRE yielded 1,390 to 2,450 kg/ha, depending on location. These yields were always increased by additional inputs of diclosulam PRE or by EPOST and POST herbicides (Table 3). The increased yields reflect the increased levels of weed control provided by the additional herbicide inputs (Tables 1 and 2). Looking at locations individually, yield from systems containing imazapic POST were higher than systems containing acifluorfen plus bentazon POST in two comparisons and equivalent in seven other comparisons.

Economic Return. Net returns from each herbicide system followed the same general trend as peanut yield (Table 3). Dimethenamid only systems netted –$308 to $329/ha. Returns were increased by additional inputs of diclosulam PRE or by EPOST and POST herbicides (Table 3). Diclosulam only systems resulted in net returns of $705 to $1657/ha. Looking at locations individually, additional inputs of EPOST and POST herbicides to diclosulam PRE alone increased net returns in five comparisons but provided equivalent net returns in seven other comparisons. The highest and most consistent net returns each year were peanut treated with diclosulam PRE (without or without dimethenamid) fb EPOST plus POST herbicides.

Early POST and POST herbicides used in this study usually increased weed control when used with dimethenamid PRE but were not always needed with diclosulam PRE. Our data indicate that diclosulam PRE in strip-tillage production controls common ragweed and eclipta 100% without additional herbicide inputs. However, control of yellow nutsedge, entireleaf morningglory, prickly sida, and pitted morningglory frequently required additional EPOST plus POST herbicide treatments. Annual grass control required a POST grass herbicide such as clethodim for season-long control. These data show that weeds can be controlled in strip-tillage peanut production and that diclosulam PRE would be of benefit.

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Table 1. Interaction of PRE, EPOST, and POST herbicide systems on yellow nutsedge and broadleaf weed control at three North Carolina locations in 1999 and 2000.

Herbicides			Yellow nutsedge												
			Lewiston		Lewiston		Lewiston		Common				Prickly	
PRE[a]	EPOST[b]	POST[c]	1999[d]		2000A		2000B		ragweed		Eclipta		sida	
			%											
Dimethenamid	None	None	32	c[e]	64	b	58	cd	82	b	31	c	0	d
Dimethenamid	Bentazon + paraquat	Acifluorfen + bentazon	67	b	97	a	55	d	97	a	78	b	87	c
Dimethenamid	Bentazon + paraquat	Imazapic	89	ab	100	a	99	a	100	a	97	a	100	a
Dimethenamid + diclosulam	None	None	83	ab	100	a	74	c	100	a	100	a	97	b
Dimethenamid + diclosulam	Bentazon + paraquat	Acifluorfen + bentazon	81	ab	100	a	88	b	100	a	100	a	100	a
Dimethenamid + diclosulam	Bentazon + paraquat	Imazapic	91	a	100	a	100	a	100	a	100	a	100	a
Diclosulam	None	None	77	ab	100	a	65	cd	99	a	100	a	94	b

Table 1. continued

Diclosulam	Bentazon + paraquat	Acifluorfen + bentazon	90	ab	100	a	63	cd	100	a	100	a	100	a
Diclosulam	Bentazon + paraquat	Imazapic	92	ab	100	a	100	a	100	a	100	a	100	a

[a] Paraquat was applied preplant to all plots at 0.70 kg ai/ha. Rates of PRE herbicides were: dimethenamid at 1.40 kg ai/ha and diclosulam at 0.027 kg ai/ha.

[b] Rates of EPOST herbicides were: bentazon at 0.28 kg ai/ha and paraquat at 0.14 kg ai/ha.

[c] Rates of POST herbicides were: bentazon at 0.56 kg/ha, acifluorfen at 0.28 kg ai/ha, and imazapic at 0.071 kg ai/ha. Clethodim was applied late postemergence at 0.14 kg ai/ha. on all plots except untreated.

[d] All locations were near Lewiston, NC. One location was used in 1999 and two locations were used in 2000.

[e] Mean separations followed by the same letter are not significantly different at 5% level of probability.

Table 2. Interaction of PRE, EPOST, and POST herbicide systems on entireleaf morningglory, ivyleaf morningglory, and pitted morningglory control at three North Carolina locations in 1999 and 2000.

Herbicides				Ivyleaf morningglory		
				Lewiston	Lewiston	
PRE[a]	EPOST[b]	POST[c]	Entireleaf morningglory	2000A	2000B	Pitted morningglory
			%			
Dimethenamid	None	None	0 d[e]	0 c	0 c	0 d
Dimethenamid	Bentazon + paraquat	Acifluorfen + bentazon	87 c	87 b	94 b	85 c
Dimethenamid	Bentazon + paraquat	Imazapic	100 a	100 a	100 a	100 a
Dimethenamid + diclosulam	None	None	88 c	98 ab	90 b	81 c
Dimethenamid + diclosulam	Bentazon + paraquat	Acifluorfen + bentazon	95 b	98 ab	99 a	93 b
Dimethenamid + diclosulam	Bentazon + paraquat	Imazapic	100 a	100 a	100 a	100 a
Diclosulam	None	None	88 bc	94 ab	100 a	84 c

Table 2. continued

Diclosulam	Bentazon + paraquat	Acifluorfen + bentazon	99 a	97 ab	100 a	98 a
Diclosulam	Bentazon + paraquat	Imazapic	100 a	100 a	100 a	100 a

[a] Paraquat was applied preplant to all plots at 0.70 kg ai/ha. Rates of PRE herbicides were: dimethenamid at 1.40 kg ai/ha and diclosulam at 0.027 kg ai/ha.

[b] Rates of EPOST herbicides were: bentazon at 0.28 kg ai/ha and paraquat at 0.14 kg ai/ha.

[c] Rates of POST herbicides were: bentazon at 0.56 kg/ha, acifluorfen at 0.28 kg ai/ha, and imazapic at 0.071 kg ai/ha. Clethodim was applied late postemergence at 0.14 kg ai/ha. on all plots except untreated.

[d] All locations were near Lewiston, NC. One location was in 1999 and two locations were in 2000..

[e] Mean separations followed by the same letter are not significantly different at 5% level of probability.

Table 3. Interaction of PRE, EPOST, and POST herbicide systems on yield, herbicide application cost, and economic return at three North Carolina locations in 1999 and 2000.

Herbicides			Yield						Herbicide application cost[f]	Economic return[g]					
PRE[a]	EPOST[b]	POST[c]	Lewiston 1999[d]		Lewiston 2000A		Lewiston 2000B			Lewiston 1999[d]		Lewiston 2000A		Lewiston 2000B	
			Kg/ha						$/ha	$/ha					
Dimethenamid	None	None	1390	d[e]	1600	c	2450	d	89.49	3	c	-308	c	329	d
Dimethenamid	Bentazon + paraquat	Acifluorfen + bentazon	3180	c	3360	b	5290	a	138.98	818	b	955	b	2408	a
Dimethenamid	Bentazon + paraquat	Imazapic	4170	b	3270	b	5080	a	160.40	1547	ab	865	b	2229	ab
Dimethenamid + diclosulam	None	None	4110	b	3930	a	4390	bc	143.82	1526	ab	1390	a	1731	bc
Dimethenamid + diclosulam	Bentazon + paraquat	Acifluorfen + bentazon	3810	b	4210	a	5230	a	193.32	1241	ab	1537	a	2309	a
Dimethenamid + diclosulam	Bentazon + paraquat	Imazapic	4210	ab	4270	a	4840	ab	214.74	1515	ab	1561	a	1995	abc

Table 3. continued

Diclosulam	None	None	4240 ab	2970 b	4020 c	103.98	1657 a	705 b	1499 c
Diclosulam	Bentazon + paraquat	Acifluorfen + bentazon	4050 b	4270 a	5080 a	153.43	1462 ab	1622 a	2236 a
Diclosulam	Bentazon + paraquat	Imazapic	4780 a	4040 a	5050 a	174.85	1987 a	1431 a	2192 ab

[a] Paraquat was applied preplant to all plots at 0.70 kg ai/ha. Rates of PRE herbicides were: dimethenamid at 1.40 kg ai/ha and diclosulam at 0.027 kg ai/ha.

[b] Rates of EPOST herbicides were: bentazon at 0.28 kg ai/ha and paraquat at 0.14 kg ai/ha.

[c] Rates of POST herbicides were: bentazon at 0.56 kg/ha, acifluorfen at 0.28 kg ai/ha, and imazapic at 0.071 kg ai/ha. Clethodim was applied late postemergence at 0.14 kg ai/ha. on all plots except untreated.

[d] All locations were near Lewiston, NC. One location was in 1999 and two locations were in 2000.

[e] Mean separations followed by the same letter are not significantly different at 5% level of probability.

[f] Application costs are calculated by summing application, herbicide cost and adjuvant cost.

[g] Economic returns are calculated by substituting the cost and yield of each herbicide systems into a farm budget.

CHAPTER 3

Flumioxazin Preplant Burndown Weed Management in Strip-Tillage Cotton (*Gossypium hirsutum*) Planted into Wheat (*Triticum aestivum*)

Abstract: Experiments were conducted at two locations in North Carolina in 1999 and 2000 to evaluate flumioxazin preplant (PP) for weed management in strip-tillage cotton planted into winter wheat cover. Flumioxazin was evaluated PP at two rates alone and in mixture with two commonly used PP herbicides and one experimental PP herbicide. Flumioxazin PP at 71 or 105 g ai/ha tank mixed with the isopropylamine salt of glyphosate (glyphosate-IP) at 1.12 kg ai/ha, paraquat at 1.05 kg ai/ha, or with the trimethylsulfonium salt of glyphosate (glyphosate-TM) at 1.12 kg ai/ha controlled common chickweed, common lambsquarters, common ragweed, Palmer amaranth, and smooth pigweed ≥ 96% at 29 to 43 d after treatment (DAT). Both glyphosate formulations and paraquat alone provided ≥ 91% control of common chickweed and henbit 29 to 43 DAT; however, control of common lambsquarters, common ragweed, large crabgrass, Palmer amaranth, and smooth pigweed was ≤ 50%. Treatments including flumioxazin injured cotton (≤ 5%) at one location. In all comparisons within a location, cotton treated with flumioxazin PP at 71 or 105 g/ha in mixture with either glyphosate formulation or paraquat provided equivalent or higher yields than cotton not treated with flumioxazin PP.

Nomenclature: Common chickweed, *Stellaria media* L. Vill. # STEME; common lambsquarters, *Chenopodium album* L. CHEAL; common ragweed, *Ambrosia artemisiifolia* L. # AMBEL; henbit, *Lamium amplexicaule* L. # LAMAM; large crabgrass, *Digitaria sanguinalis* (L.) Scop. # DIGSA; Palmer amaranth, *Amaranthus palmeri* L. # AMAPA;

smooth pigweed, *Amaranthus hybridus* L. # AMACH; wheat, *Triticum aestivum* L., cotton, *Gossypium hirsutum* L., ‘Paymaster 1218 RRBG’, ‘Paymaster 1220 RRBG’.

Additional index words: Burndown treatment, cover crops.

Abbreviations: DAT, days after treatment; isopropylamine salt of glyphosate, glyphosate-IP; trimethylsulfonium salt of glyphosate, glyphosate-TM; PRE, preemergence; PP, preplant; POST, postemergence; PDS, postemergence-directed spray; WAP, weeks after planting.

Introduction

Many cotton growers in the southeast are utilizing reduced-tillage operations address concerns about soil erosion, water availability, and sandblasting of young cotton plants on windy early spring days in sandy soils (Bradley 1995; York 1995). Legumes such as vetch (*Vicia sativa*, L.) or crimson clover (*Trifolium incarnatum,* L.) or small-grains such as wheat or rye (*Secale cereale* L.), are commonly utilized as winter cover in reduced tillage systems and must be desiccated two to three wks before planting (York 1995). Small-grain cover crops are preferred over legumes for no-till cotton because they are easier to establish, easier to kill, provide more protection from soil erosion during the fall and winter months, and provide more persistent mulch and better weed suppression (Naderman et al. 2002). Commonly utilized preplant (PP) winter cover crop burndown treatments in cotton include paraquat and glyphosate-IP (Brown and Whitwell 1985; White and Worsham 1990; York 1995). Both herbicides provide inexpensive winter cover burndown and broad-spectrum weed control (Wilcut et al. 1995). However, neither herbicide effectively controls all weeds or provide residual weed control.

Glyphosate-resistant cotton cultivars are planted on greater than 75% of the North Carolina cotton hectarage (A. C. York, K. Edminsten, North Carolina State University, personal communication). The development of herbicide-resistant cotton cultivars and new herbicides registered for postemergence (POST) application over-the-top of cotton has allowed growers to utilize total POST weed management systems that fit well in reduced tillage operations. Approximately 35 to 40% of North Carolina cotton hectarage does not receive soil-applied herbicide treatments at planting (A. C. York, personal communication). However, the exclusion of residual preemergence (PRE) herbicides at planting allows early-season weed interference which may be detrimental to cotton yield (Askew and Wilcut 1999; Buchanan and Burns 1970; Clewis et al. 2000; Culpepper and York 1998; Scott et al. 2001b). A residual herbicide applied PP in mixture with non-selective herbicides like glyphosate-IP or paraquat could increase the flexibility of POST application timings while minimizing early-season weed competition.

Flumioxazin is a *N*-phenylphthalimide herbicide registered for preemergence (PRE) treatment in peanut (*Arachis hypogaea* L.) and as an early-preplant burndown treatment in cotton (Anonymous 2002; Askew et al. 1999; Clewis et al. 2002; Grichar and Colburn 1996). Research indicates that flumioxazin may be applied as a postemergence-directed spray (PDS) or PP treatment in cotton (Altom et al. 2000; Askew et al. 2002; Cranmer et al. 2000; Main et al. 2000;Wilcut et al. 2000). Cotton injury due to flumioxazin PP treatments may occur and is influenced by application timing in respect to planting (Askew et al. 2002). Cotton planted no-till into undisturbed cotton and corn stubble was injured ≤ 12% if flumioxazin was applied PRE on the day of planting, but ≤ 3% if application was made at least 2 wks before planting.

Flumioxazin PRE controls common lambsquarters, common ragweed, entireleaf morningglory (*Ipomoea hederacea* var. *integruiscula* L.), ivyleaf morningglory (*Ipomoea* *hederacea* L. Jacq.), Palmer amaranth, pitted morningglory (*Ipomoea lacunosa* L.), prickly sida (*Sida spinosa* L.), smooth pigweed, and tall morningglory (*Ipomoea purpurea* L. Roth) (Askew et al. 2002; Clewis et al. 2002; Niekamp et al. 1999). Although flumioxazin would appear to be a good fit for PP application alone or in mixture with various PP herbicides in cotton, existing winter cover, cotton, and weed responses to these treatments are unknown. Therefore, field studies were conducted to evaluate control of an existing wheat cover and weeds with flumioxazin applied PP alone and in mixture with various PP herbicides. Additionally cotton response, kept weed free from the 4-leaf stage to harvest, to flumioxazin PP was evaluated.

Materials and Methods

Field experiments were conducted at the Upper Coastal Plain Research Station located near Rocky Mount, NC and at the Central Crops Research Station near Clayton, NC in 1999 and 2000. Soil at both locations was a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudults) with 1.1% organic matter and pH of 5.7 at Rocky Mount and 1.8% organic matter and pH of 5.8 at Clayton. Treatment combinations reflected a three by four factorial treatment arrangement of residual (flumioxazin) and non-residual (glyphosate-IP, glyphosate-TM, and paraquat) PP herbicides. Residual treatments included flumioxazin at 71 g ai/ha or 105 g ai/ha alone or in mixture with one of the following non-residual herbicides: glyphosate-IP or glyphosate-TM at 1.12 kg ai/ha or paraquat at 1.05 kg ai/ha. Glyphosate-IP or glyphosate-TM at 1.12 kg/ha or paraquat at 1.05 kg/ha were also applied alone and a non-PP control was included to complete the factorial treatment arrangement. A hand-weeded control was not included in the design as previous field research showed that cotton yield was not reduced by flumioxazin PP treatments (Askew et al. 2002). A nonionic surfactant (NIS) at 0.25% (v/v) was included in the paraquat alone herbicide treatment and crop oil concentrate (COC) at 1.67% (v/v) was included with all flumioxazin-containing treatments.

Soft red winter wheat cover (22 to 25 seedlings per square foot) was established in cotton stubble utilizing a no-till drill at both locations each year between October 20th and November 8th. The following spring, the wheat cover and emerged weeds were broadcast treated with one of the previously mentioned treatments using a compressed CO_2 backpack sprayer delivering 140 L/ha at 147 kPa. The wheat was at the 2 to 3-tiller stage while winter annual weeds in the untreated PP check (common chickweed, 1 to $20/m^2$; henbit, 1 to $20/m^2$) ranged from cotyledon to 4-leaf in size at time of PP application. Application dates were April 5, 1999 at Clayton; March 30, 1999 at Rocky Mount; April 10, 2000 at Clayton; and April 14, 2000 at Rocky Mount.

Land preparation included opening the soil with the subsoiler shank of a Ro-Till planter with the planter units removed to open the soil and destroy plowpans beneath the rows 2 wk prior to planting. Attached to the planter, fluted coulters smoothed the soil and broke up large clods. Rolling crumblers that were mounted immediately behind the fluted coulters served to further smooth the seedbed. Approximately 60% of the surface residue remained in the tilled area and 90 to 95% of the non-tilled area was covered with residue after seedbed preparation. Cotton seed were then planted using a conventional planter. Glyphosate-IP-resistant cotton cultivars, ‘Paymaster 1220 RRBG’ in 1999 and ‘Paymaster 1218 RRBG’ in 2000, were planted into seedbeds at 13 seeds per m of row on May 5, 1999 at Clayton, May 12, 1999 at Rocky Mount, May 9, 2000 at Clayton, and May 24, 2000 at Rocky Mount. Planting dates for each location varied following PP application due to weather. The interval between PP treatments and planting was 29 to 43 d in 1999 and 2000, respectively, between the two locations. However, within a location over years, the time interval between PP treatments and planting was 29 to 30 d at Clayton and 40 to 43 d at Rocky Mount. Askew et al. (2002) reported no influence on cotton treated with flumioxazin PP at 2 to 10 wks before planting. Emerged summer annual weeds at time of planting in the untreated PP check (common lambsquarters, 15 to 50/m^2; common ragweed, 10 to 60/m^2; large crabgrass, 20 to 35/m^2; Palmer amaranth, 15 to 40/m^2; and smooth pigweed, 12 to 30/m^2) ranged from cotyledon to 2-leaf. The Clayton location had higher densities of emerging summer annual weeds compared to the Rocky Mount location (data not shown). When cotton reached the 4-leaf growth stage (26 to 28 d after planting), glyphosate-IP was applied over-the-top at 1.12 kg/ha to control emerged weeds in all plots. The glyphosate-IP treatment was applied June 5, 1999 at Clayton; June 7, 1999 at Rocky Mount; June 6, 2000 at Clayton; and June 19, 2000 at Rocky Mount, 57 to 69 d after the PP treatments. This treatment is standard for weed management in glyphosate-IP-resistant cotton in North Carolina and according to the glyphosate label (Anonymous 1999; Culpepper and York 1998; Scott et al. 2001b). Clethodim at 0.14 kg ai/ha plus 1.0% (v/v) COC was applied late-POST for annual grass control. A late PDS application of prometryn at 1.12 kg ai/ha plus MSMA at 2.24 kg ai/ha plus 0.25% (v/v) NIS and hand weeding as needed were used to keep plots weed free. This approach allowed us to evaluate early-season weed control (up to planting) with PP treatments and to ascertain weed free crop response (after 4-leaf cotton) to PP treatments. The experimental design was a randomized complete block with a 3 by 4 factorial treatment arrangement and treatments were replicated three times. Plots at Rocky Mount were four 92 cm rows wide and 9.1 m long. Plots at Clayton were four 97 cm rows wide and 9.1 m long.

Cotton injury was evaluated 2 and 5 wks after planting (WAP). Visual control estimates of winter annual weeds present at time of PP application as well as evaluation of summer annual weed control were recorded at planting. Common chickweed, common lambsquarters, common ragweed, henbit, large crabgrass, Palmer amaranth, smooth pigweed, and wheat cover were each evaluated for control by PP treatments. Weed control and cotton injury, based on visual leaf discoloration, visual stunting, and visual biomass reductions as compared to the non PP-treated control, were estimated on a scale of 0 (no injury symptoms) to 100 (complete death of all plants or no plants present) (Frans et al. 1986). The center two rows of each plot were harvested once for lint and seed with a spindle picker modified for small-plot harvesting. Harvest dates were November 25, 1999 at Clayton, November 11, 1999 at Rocky Mount, October 17, 2000 at Clayton, and October 31, 2000 at Rocky Mount.

All data were subjected to analysis of variance (ANOVA) using the general linear models procedure in SAS (SAS 1998) to evaluate the effect of a three (residual PPI) by four (non-residual PPI) factorial herbicide treatment arrangement. Herbicide treatments were considered fixed effects while year, location, and year by location effects were considered random variables. Non-transformed data for visual evaluations are presented because arcsine square root transformation did not affect data interpretation. ANOVA was conducted with and without the PP control prior to ensure the control did not bias the conclusions since visually estimated weed control ratings were zero. Conclusions are based on the inclusion of the checks in the analysis. Means for appropriate main effects and interactions were separated using Fisher’s protected LSD test at $P = 0.05$. Where interactions occurred, data are presented separately and where interactions did not occur, data are combined.

Results and Discussion

Cotton Injury. At early-evaluation (2 WAP), all treatments that included flumioxazin injured cotton ≤ 5% at Clayton in 2000 (data not shown) and were comparable to injury levels reported by Askew et al. (2002). By 5 WAP, no cotton injury was observed in either year (data not shown). Although injury may occur when flumioxazin is applied PP, the levels of injury observed in this study are not likely to be agronomically significant. Fluometuron PRE has been widely used in North Carolina for over two decades and early season cotton injury of 15% is not uncommon (A. C. York, personal communication). Cotton is able to recover from less than 25% early-season injury and avoid yield loss (Chandler and Savage 1980; Hayes et al. 1981; Walsh et al. 1993).

Wheat Cover Control. There was no year or location effect for control of the wheat cover; therefore, data were combined over years and locations. Flumioxazin alone controlled the wheat cover ≤ 30% at planting, regardless of rate (Table 1). Flumioxazin at 71 or 105 g/ha in mixture with either glyphosate formulation, or either glyphosate formulation alone controlled the wheat cover ≥ 96% at planting. Paraquat alone or in mixture with either rate of flumioxazin controlled the wheat cover ≤ 83% at planting.

Weed Control. There was no year or location effect for weed control; therefore, data were combined over years and locations. Flumioxazin PP at both rates alone or in mixture with either glyphosate formulation or paraqat controlled common chickweed, common lambsquarters, common ragweed, henbit, Palmer amaranth, and smooth pigweed ≥ 96% at planting 29 to 43 d after PP treatment (Table 1). Flumioxazin at 71 g/ha controlled large crabgrass 65% at 29 to 43 d after PP treatment. Increasing the flumioxazin rate to 105 g/ha increased large crabgrass control to 86%. Flumioxazin does provide some residual control of grasses; however, it will not provide season-long control (Askew et al. 1999; Grichar and Colburn 1996). The addition of either glyphosate formulation or paraquat did not improve large crabgrass control. Glyphosate-IP and paraquat alone provided complete (100%) control of common chickweed and henbit at planting, 29 to 43 d after PP treatment. Glyphosate-TM alone controlled common chickweed and henbit 100 and 91%, respectively, 29 to 43 DAT. However, control of common lambsquarters, common ragweed, large crabgrass, and smooth pigweed by either glyphosate formulation or paraquat alone was < 50% at 29 to 43 d after PP application. These herbicides do not provide residual control, thus later germinating weeds would escape. These weeds are typical summer annuals found in the Southeast and will germinate at least into late June (authors' personal observations). Research trials in peanut with flumioxazin at similar rates have also shown residual control of common lambsquarters, common ragweed, and smooth pigweed (Askew et al. 1999; Scott et al. 2001a, 2002)

Cotton Yield. There was a year by location interaction for cotton yield; therefore, locations are presented separately. At Clayton in 1999, cotton treated with flumioxazin at both rates alone or in mixture with glyphosate-IP, glyphosate-TM, or paraquat yielded similarly (660 to 700 kg lint/ha) (Table 2). Cotton treated with either glyphosate formulation or paraqat alone yielded less (500 to 520 kg/ha). The non-PP control yielded 280 kg/ha. At Rocky Mount in 1999, cotton treated with flumioxazin at both rates alone or in mixture with either glyphosate formulation or paraqat provided equivalent lint yields (750 to 820 kg/ha). Cotton treated with either glyphosate formulation or paraquat alone yielded less (700 to 710 kg/ha). The non-PP control yielded 610 kg/ha. A typical cotton yield for North Carolina is around 800 kg/ha (North Carolina Dept. of Agriculture Statistics 1998-2000). Yield reductions at the

Clayton location are likely due to increased densities of emerging summer annual weeds compared to Rocky Mount.

At Clayton in 2000, lint yields from cotton treated with flumioxazin at either rate in mixture with either glyphosate formulation or paraqat yielded similarly (880 to 960 kg/ha). Cotton treated with either rate of flumioxazin, either glyphosate formulation, or paraqat applied alone yielded less (720 to 740 kg/ha). The non-PP control yielded 560 kg/ha. At Rocky Mount in 2000, cotton treated with flumioxazin at both rates alone or in mixture with either glyphosate formulation or paraqat yielded more (1590 to 1680 kg/ha) than the non-PP control and cotton treated with either glyphosate formulation or paraqat alone (1140 to 1190 kg/ha). The increased yield at Rocky Mount may be attributed to the ideal growing conditions that were present throughout the 2000 season at this location (weather data not shown). In all comparisons within a location, cotton treated with flumioxazin at 71 or 105 g/ha in mixture with either glyphosate formulation or paraqat provided yields at least equivalent and frequently greater than cotton treated with either glyphosate formulation or paraqat alone. Because flumioxazin minimally injured cotton 2 WAP at one location in one year and these experiments were kept weed free after cotton reached the 4-leaf stage, we believe differences in yield reflect early season weed interference. Similar results showing yield reductions from early season weed interference have been reported (Askew and Wilcut 1999; Buchanan and Burns 1970; Clewis et al. 2000; Culpepper and York 1998; Scott et al. 2001b). In previous research, cotton yields were not influenced by flumioxazin at 70 g/ha PP when applied between 0 and 10 wks prior to planting (Askew et al. 2002).

These data suggest that flumioxazin is a safe herbicide for use as a PP treatment 29 to 43 d before cotton planting on similar soils. These data also support the flumioxazin PP label for burndown uses at 71 g/ha at least 30 d before planting cotton. The inclusion of a residual herbicide such as flumioxazin in a PP treatment should reduce early season weed interference in production systems that do not use herbicides or tillage at planting to control weeds. Because many reduced-tillage systems plant glyphosate-resistant cultivars in North Carolina, flumioxazin PP may reduce the density of problematic weeds found in reduce-tillage and glyphosate-resistant cotton systems. Also, the use of flumioxazin PP should delay the first glyphosate application in glyphosate-resistant cotton systems compared to systems that exclude residual PP herbicides.

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Table 1. Wheat and weed control at planting by preplant herbicide treatments applied 29 to 43 d prior to planting.

Preplant herbicides[a]	WHEAT	AMACH[b]	AMBEL	AMAPA	CHEAL	DIGSA	LAMAM	STEME
	% control							
Flumioxazin 71 g/ha	30	98	98	96	100	65	80	98
Flumioxazin 105 g/ha	27	100	99	100	100	86	75	98
Flumioxazin 71 g/ha plus glyphosate-IP 1.12 kg/ha	96	97	98	96	100	63	97	100
Flumioxazin 105 g/ha plus glyphosate-IP 1.12 kg/ha	98	100	100	100	100	82	98	100
Flumioxazin 71 g/ha plus paraquat 1.05 kg/ha	78	97	100	98	100	67	100	100
Flumioxazin 105 g/ha plus paraquat 1.05 kg/ha	77	100	100	97	100	80	100	100
Flumioxazin 71 g/ha plus glyphosate-TM 1.12	96	97	100	98	100	69	99	96
Flumioxazin 105 g/ha plus glyphosate-TM 1.12	99	100	100	99	100	80	100	100

Table 1. continued

Glyphosate-IP 1.12 kg/ha	99	22	12	0	47	30	100	100
Paraquat 1.05 kg/ha	83	19	18	1	50	33	100	100
Glyphosate-TM 1.12	98	17	15	0	48	41	91	100
LSD	13	27	19	3	29	22	16	3

[a] All flumioxazin-containing treatments included crop-oil concentrate at 1.67% (v/v). The paraquat alone treatment included nonionic surfactant at 0.25% (v/v). When cotton reached the 4-leaf growth stage (26 to 28 d after planting), glyphosate-IP was applied over-the-top at 1.12 kg/ha to control emerged weeds in all plots.

[c] Abbreviations and weed size and densities in the untreated PP check at planting: LAMAM = henbit (4-leaf, 1 to 20/m^2), STEME = common chickweed (4-leaf, 15 to 20/m^2) AMACH = smooth pigweed (cotyledon to 2-leaf, 12 to 30/m^2), AMAPA = Palmer amaranth (cotyledon to 2-leaf, 15 to 40/m^2), AMBEL = common ragweed (cotyledon to 2-leaf, 10 to 60/m^2), CHEAL = common lambsquarters (cotyledon to 2-leaf, 15 to 50/m^2), DIGSA = large crabgrass (1 to 2 to leaf, 20 to 35/m^2).

Table 2. Cotton seed lint yield after preplant herbicide treatments at two locations in North Carolina in 1999 and 2000.

Preplant herbicides[a]	Clayton 1999	Rocky Mount 1999	Clayton 2000	Rocky Mount 2000
	(kg/ha)			
Flumioxazin 71 g/ha	660	800	790	1620
Flumioxazin 105 g/ha	700	750	800	1600
Flumioxazin 71 g/ha plus glyphosate-IP 1.12 kg/ha	680	800	900	1650
Flumioxazin 105 g/ha plus glyphosate-IP 1.12 kg/ha	680	750	880	1670
Flumioxazin 71 g/ha plus paraquat 1.05 kg/ha	700	820	960	1680
Flumioxazin at 105 g/ha plus paraquat 1.05 kg/ha	670	800	900	1650
Flumioxazin at 71 g/ha plus glyphosate-TM 1.12 kg/ha	680	760	930	1590

Table 2. continued

Flumioxazin 105 g/ha plus glyphosate-TM 1.12 kg/ha	700	800	900	1620
Glyphosate-IP 1.12 kg/ha	520	710	740	1190
Paraquat 1.05 kg/ha	500	700	720	1160
Glyphosate-TM 1.12 kg/ha	500	710	720	1140
Non-PP control	280	610	560	1160
LSD	100	80	110	130

[a] All flumioxazin-containing treatments included crop-oil concentrate at 1.67% (v/v). The paraquat alone treatment included nonionic surfactant at 0.25% (v/v). When cotton reached the 4-leaf growth stage (26 to 28 d after planting), glyphosate-IP was applied over-the-top at 1.12 kg/ha to control emerged weeds in all plots.

CHAPTER 4

Physiological Basis for Cotton Tolerance to Flumioxazin Applied Postemergence-directed

Abstract. Previous research has shown that flumioxazin, a herbicide being developed as a postemergence-directed spray (PDS) in cotton, has the potential to injure cotton less than 30 cm tall if the herbicide contacts green stem material due to rain splash or misapplication. In response to this concern, young cotton plants (five-leaf) with chlorophyllous stems as well as older cotton plants (16-leaf) with mature bark were treated with a PDS containing flumioxazin plus crop oil concentrate (COC) or non-ionic surfactant (NIS). Stems of treated plants and non-treated plants at the respective growth stage were cross-sectioned and then magnified and photographed using bright-field microscopy techniques. More visible injury was evident in younger cotton. Also, there was a decrease in treated-stem diameter and an increase in visible injury with use of COC compared to NIS in younger cotton. The influence of plant growth stage and harvest time on the absorption, translocation, and metabolism of ^{14}C-flumioxazin in cotton was investigated. Total ^{14}C absorbed at 72 hours after treatment (HAT) was 77, 76, and 94% of applied at 4-, 8-, and 12-leaf growth stages, respectively. Cotton at the 12-leaf stage absorbed more ^{14}C within 48 HAT than was absorbed by 4- or 8-leaf cotton by 72 HAT. A majority (31-57%) of applied ^{14}C remained in the treated stem for all growth stages and harvest times. Treated cotton stems at all growth stages and harvest times contained higher concentrations (Bq/gram tissue dry wt.) of ^{14}C than any other tissue. Flumioxazin metabolites made up less than 5% of the radioactivity found in the treated stem. Due to the undetectable levels of metabolites in other tissues when flumioxazin was applied PDS, flumioxazin was then applied foliarly to determine if flumioxazin transported to the leaves may be metabolized. In foliar-treated cotton, flumioxazin metabolites in the treated leaf of four-leaf cotton totaled 4% of the recovered ^{14}C 72 HAT. Flumioxazin metabolites in the treated leaf of 12-leaf cotton totaled 35% of the recovered ^{14}C 48 HAT. These data suggest that differential absorption, translocation, and metabolism at various growth stages, as well as the development of a bark layer, are the bases for differential tolerances of cotton to flumioxazin applied PDS.

Key words: Absorption, translocation, metabolism.

Introduction

Flumioxazin was recently registered for preemergence use in peanut (*Arachis hypogaea* L.) as well as a preplant burndown treatment in cotton, and it is also being developed as a postemergence-directed spray (PDS) treatment in cotton (Anonymous 2002; Askew et al. 2002; Price and Wilcut in press). Flumioxazin acts by inhibiting protoporphyrinogen oxidase (protoporphyrin IX:oxygen oxidoreductase, EC 1.3.3.4) (Anonymous 1998; Cranmer et al. 2000). Inhibition of this enzyme induces accumulation of protoporphyrin IX due to uncontrolled autooxidation of the substrate (Duke et al. 1991). As protoporphyrin IX accumulates and is impinged by light, toxic oxygen radicals are generated which lead to degradation of plasmalemma and tonoplast membrane lipids and irreversible damage of their membrane structure and function in susceptible plants.

Acifluorfen, lactofen, and sulfentrazone are herbicides that have similar modes of action as flumioxazin and are registered in soybean (*Glycine max* L.). Plant species differ in their tolerance to these herbicides due to differential absorption, translocation, and metabolism. Foliar-applied ^{14}C-acifluorfen was absorbed slowly by tolerant soybean leaves, with only 4% absorbed 48 hours after treatment (HAT) compared to 11% by both susceptible common ragweed (*Ambrosia artemisiifolia* L.) and common cocklebur (*Xanthium strumarium* L.) (Ritter and Coble 1981). In a similar study, tolerant ivyleaf morningglory (*Ipomoea hederacea* L.) absorbed 29% of applied ^{14}C-acifluorfen and 36% of applied ^{14}C-lactofen, while susceptible or sensitive pitted morningglory (*Ipomoea lacunosa* L.) absorbed 68% of applied ^{14}C-acifluorfen and 36% of applied ^{14}C-lactofen with less than 1% of applied herbicide translocated out of the treated leaf in either morningglory species (Higgens et al 1988). Comparing sicklepod [*Senna obtusifolia* L. (Irwin and Barnaby)] and coffee senna (*Cassia occidentalis* L.) susceptibility to sulfentrazone, Dayan et al. (1996) found that sicklepod, which exhibits considerable tolerance, metabolized 92% of applied sulfentrazone at 9 HAT. Coffee senna, a sensitive species, absorbed 74% more sulfentrazone than sicklepod, and only metabolized 17% by 9 HAT. In another study, Dayan et al. (1997) reported no differences in absorption and translocation of sulfentrazone between relatively tolerant and less tolerant soybean cultivars. Tolerance was found to be due to differential metabolism and differential tolerance to herbicide–induced peroxidative stress.

Localized injury has been observed on chlorophyllous green cotton stems less than 30 cm tall when flumioxazin was applied as a PDS (Altom et al. 2000). Severe injury may occur when flumioxazin contacts cotton foliage, as when heavy rain splashes treated soil onto leaves, or when the herbicide is misapplied (Wilcut et al. 2000). Previous research has shown that flumioxazin can be applied safely as a precise PDS to 15- to 30-cm tall cotton (Askew et al. 2002; Main et al. 2000). Less injury is observed on older cotton plants (approximately 12-leaf) where a layer of bark develops on the stem up to approximately 10 cm above the soil surface. This increased tolerance may be due to decreased flumioxazin absorption into the stem, increased translocation out of the stem, or increased metabolism by more mature plants. The presence of a bark layer composed of highly lignified cells may also minimize localized flumioxazin injury. The objectives of this research were to evaluate the absorption, translocation, and metabolism of ^{14}C-flumioxazin as well as herbicidal damage to stem tissue in cotton as influenced by growth stage and harvest times.

Methods and Materials

Plant Material and Growth Conditions

Cotton plants (DeltaPine 5415RR) were grown in 15-L pots containing Metro-Mix 360 in a plastic greenhouse maintained at approximately 25 ± 2 C. There was a 16-h photoperiod of natural and supplemental metal halide lighting with an average midday photosynthetic flux density of 700 µmol $m^{-2}s^{-1}$. Four seed were sown and seedlings were thinned to one plant per pot at the two-leaf stage. Studies were arranged as randomized complete block designs with three replications of treatments to evaluate absorption and translocation of flumioxazin. Each study was repeated over time. Two separate studies were conducted to evaluate the metabolism of flumioxazin. These studies were also repeated in time.

Microscopy

To visually assess the type and depth of flumioxazin injury to cotton tissues, young cotton plants (five-leaf) with chlorophyllous stems as well as older cotton plants (16-leaf) with mature bark stems were treated with a PDS containing 0.071 kg ai/ha flumioxazin plus 1.0% (v/v) crop oil concentrate (COC) or 0.25% (v/v) non-ionic surfactant (NIS) using a backpack sprayer with an output of 140 L ha^{-1}. Stems of treated and non-treated plants were cross sectioned by hand using a razor blade at 5 cm above the soil surface nine days after treatment. Stem sections were visualized under a dissecting microscope and photographed with a digital camera.

Absorption and Translocation

Plants at the 4-, 8-, and 12-leaf growth stages were treated with [phenyl-^{14}C]-labelled flumioxazin. A micro-syringe was used to deliver ten 1-µL droplets of ^{14}C-flumioxazin plus 0.25% (v/v) NIS in water containing 1250 Bq ^{14}C-flumioxazin [specific activity ^{14}C-flumioxazin was 106 mCi/mmol, 94.2% radiopurity] to a 5-cm^2 section of stem just above soil level to simulate a precise PDS application. Treated plants were harvested 4, 24, 48, or 72 HAT. At harvest, the treated stem from each plant was washed with 10 mL of methanol:water (1/1, v/v) and 0.25% (v/v) NIS solution to remove non-absorbed herbicide from the stem surface. A 1 mL aliquot from each stem wash was then added to 25 mL of scintillation cocktail and quantified by liquid scintillation spectroscopy (LSS). The remainder of the plant was then sectioned into treated and non-treated portions the stem, mature fully expanded leaves, immature leaves and buds, roots, and when applicable, reproductive squares and bolls. These parts were then placed into paper bags and dried at 65°C for at least 72 h. The plant parts were then ground with a coffee grinder and a 100- to 200-mg subsample was oxidized in a biological oxidizer, where ^{14}C was trapped in scintillation cocktail and radioactivity quantified by LSS.

Data were subjected to analysis of variance (ANOVA) using SAS. Residuals were plotted, and logarithmic transformations conducted on data where variance increased with increasing means. Following ANOVA, treatment or log-transformed treatment means were compared using Fisher's Protected LSD test at the 5% probability level. Where appropriate, regressions were used to explain the relationship of measured response over time.

Metabolism

To evaluate whether growth stage influenced metabolism, two separate studies were conducted. Cotton plants were grown and treated with 1250 Bq ^{14}C-flumioxazin on the stem (4-, 8-, and 12-leaf cotton). Due to the undetectable levels of metabolites in tissue other than the treated stem when flumioxazin was applied PDS, flumioxazin was then applied foliarly to determine if flumioxazin transported to the leaves could be metabolized. ^{14}C-flumioxazin containing 5830 Bq was spotted on the youngest fully expanded leaf (4- and 12-leaf cotton) and harvested as previously described. At harvest, partitioned plant parts were immediately placed in a freezer at –30 C for further analysis. Based on absorption and translocation data from the previous study, we assumed only treated stems and treated leaves contained sufficient amounts of ^{14}C for detection of metabolites.

Stems or leaves were ground into a fine powder with a mortar and pestle under liquid nitrogen. The plant material was then placed into a 20-mL centrifuge vial and 5 mL of acetone was added to extract ^{14}C-flumioxazin and possible metabolites. The samples were vortexed for 1 min and were allowed to sit for 2 h. The tissue samples were then centrifuged for 15 min at 2000 g. The supernatant was decanted and filtered for each sample. The tissue was re-extracted twice as above and the resulting supernatant was combined and evaporated to a consistent volume of approximately 300 µL. The remaining extracted stem or leaf material was oxidized, and non-extractable ^{14}C quantified as previously described. The supernatant was analyzed utilizing Waters® high performance liquid chromatography instrumentation (HPLC) to separate the parent herbicide from possible metabolites, which were detected and quantified using a Waters® UV-spectrophotometer and a Packard® in-line radiochemical-detector. Radioactive trace peaks were integrated with FLOW-ONE®

software with background excluded from peak area calculations. Comparing retention times from a ^{14}C-flumioxazin standard and the retention times within samples identified the non-metabolized ^{14}C-flumioxazin parent.

The HPLC conditions were a modification of those provided by Valent USA. The initial mobile phase was acetonitrile plus 0.01% aqueous trifluoroacetic acid 25:75 (v/v), followed by a linear increase to 100% acetonitrile over 20 min. The 100% acetonitrile mobile phase was then held constant until 30 min after sample injection. The mobile phase flow rate was 1 mL min^{-1}. The flow rate for scintillation cocktail to the radiochemical detector was 3 mL min^{-1}. A reverse-phase C-18 column (25 by 4.6-mm column dimensions, Alltech, 10-μm particle size) was used for the separation. All solvents were HPLC grade and all injection volumes were 25 μL. Statistical procedures were similar to those previously described for absorption and translocation data.

Results and Discussion

Visible injury by flumioxazin

Visible injury caused by flumioxazin was evident in younger (five-leaf stage) cotton than in older (16-leaf) cotton (Figures 1-6). The adjuvant added to flumioxazin also affected the severity of injury to cotton stem tissue. Treatments containing COC plus flumioxazin decreased treated-stem diameter and increased the depth of flumioxazin injury in stems of five-leaf cotton compared to the non-treated and NIS plus flumioxazin (Figures 1-3). Visible injury and decreases in stem diameter were not evident in any flumioxazin treatment to 16-leaf cotton regardless of surfactant (Figures 4-6).These micrographs demonstrate that flumioxazin treatments are more injurious to five-leaf cotton than 16-leaf cotton, likely due to the presence of a bark layer in 16-leaf cotton which is likely less sensitive to flumioxazin than chlorophyllous stem tissue.

Absorption and Translocation

Growth stage by run and harvest timing by run interactions were not significant ($P > 0.05$), thus data were combined over experimental runs. The effects of growth stage and harvest time significantly influenced the absorption and translocation of ^{14}C by cotton. At 4 HAT, total absorption of ^{14}C-flumioxazin was 39, 40, and 60% for 4-, 8-, and 12-leaf growth stages, respectively (Table 1). Total ^{14}C absorbed by 72 HAT was 78, 76, and 95% at 4-, 8-, and 12-leaf growth stages, respectively. Overall, absorption of ^{14}C-flumioxazin in the current study was higher than previously reported by Ritter and Coble (1981) and Higgins et al. (1988) for herbicides (acifluorfen and lactofen, respectively) with a similar mode of action or in the chemistry of the compound. These differences may reflect differences in our application to the lower cotton stem verses foliar application to soybean. Wills (1978) found that translocation of ^{14}C-glyphosate was greater following application to the mature lower stem than when applied to mature lower leaves or to immature upper stem or leaves of cotton. ^{14}C absorption by 12-leaf cotton within 24 HAT exceeded that of 4- or 8-leaf cotton at 72 HAT (Figure 7). Despite greater ^{14}C absorption by 12-leaf cotton, visible injury at this stage is far less than that observed in younger cotton (personal observation). Pline et al. (2001) reported greater absorption of stem-applied ^{14}C-glyphosate by 12-leaf cotton than by 4- or 8-leaf cotton. These studies, as well as the current study, suggest that herbicide entry through the bark and cambium tissue layers of a mature cotton stem is greater than through other tissues. In the case of flumioxazin, this tissue may be less sensitive to injury than foliar or green stem tissue due to lower protoporphyrin IX content in this lignified tissue (Duke

1974-1994). A lack of stem tissue damage by flumioxazin may allow continued absorption of the herbicide over time.

The majority (31 to 57%) of applied ^{14}C remained in the treated stem for all growth stages and harvest times. Only 1 to 2% of ^{14}C was translocated to organs such as mature leaves, immature leaves and buds, untreated stem, and roots of four-leaf cotton by 4 HAT. However, over time, translocation increased in four-leaf cotton to 11% in mature leaves, 3% in immature leaves and buds and 6% in untreated stem, but remained at only 1% in roots at 72 HAT. Translocation of absorbed ^{14}C by eight-leaf cotton was greater to mature leaves than at the four-leaf stage at 4 HAT, but only 2% or less ^{14}C was translocated to immature leaves and buds, roots, and the non-treated stem portion (Table 1). Translocation of absorbed ^{14}C over time in eight-leaf cotton increased to 6% in mature leaves and in untreated stem, but did not increased in immature leaves and buds or roots by 72 HAT. This increase was similar to that of four-leaf cotton. Roots of 12-leaf cotton contained at least three times more ^{14}C than roots of 4- and 8-leaf cotton at all harvest times.

Treated cotton stems at all growth stages and harvest times contained greater concentrations (Bq/gram tissue dry wt. of cotton) of ^{14}C than any other tissue (Tables 2, 3, and 4). At the four-leaf stage, the concentration of ^{14}C in all other tissues remained below 10% of the concentration detected in the treated stem (Table 2). The injury associated with flumioxazin application to green stems at this stage may limit the amount of ^{14}C translocated out of the treated stem. ^{14}C-flumioxazin applied to 8- and 12-leaf cotton was more likely to translocate out of the treated stem and accumulate in other tissues. ^{14}C applied to eight-leaf cotton initially accumulated in the mature leaf tissue (4 to 48 HAT) but later began to accumulate in stem tissue (72 HAT) (Table 3). ^{14}C-flumioxazin applied to 12-leaf cotton tended to accumulate in roots over time (Table 4). As tissues increase in mass from the four-leaf to the 12-leaf stages, one would expect the concentration of ^{14}C to decrease as the herbicide is diluted by the increase in biomass. This decrease was observed with the treated stem tissue; however, ^{14}C concentration increased in most other tissues from the 4- to 8-leaf stage despite the increase in biomass. The increase in ^{14}C-concentration in other tissues would suggest that considerably more translocation is occurring in 8- and 12-leaf cotton than four-leaf cotton, potentially diluting the concentration in treated stems to a less injurious concentration. In 12-leaf cotton, less than 5% of absorbed ^{14}C translocated to reproductive structures. However, on a Bq/plant dry weight concentration basis, this represents at least one-tenth, and up to one-third the concentration of ^{14}C detected in treated stems. Whether this concentration would affect normal fruit development in unknown. However, lint yield was not influenced by flumioxazin treatment in field studies (Askew et al. 2002).

Metabolism

Experimental run by main effect interactions were not significant for the two studies ($P > 0.05$), so data were combined over runs. Harvest time significantly influenced metabolism of foliar-applied ^{14}C-flumioxazin but not stem-applied ^{14}C-flumioxazin. Extraction of absorbed radioactivity was greater than 90%. Of the recovered radioactivity, 10% remained bound in the plant debris after extraction. The parent flumioxazin eluted at 22.5 min. Other ^{14}C peaks assumed to be metabolites eluted between 15.1 and 23.3 min. Thus, the amount of herbicide metabolites in the stem or leaves was set equal to the sum of these metabolites.

Flumioxazin metabolites recovered in the stem totaled less than 0.05% of total applied ^{14}C and around 5% of the recovered ^{14}C found in the treated stem (data not shown). Accumulation of metabolites in treated stem portions of 4-, 8-, and 12-leaf at 4, 24, 48, and

72 HAT was not significantly different (data not shown). The main effects of growth stage as well as harvest timing were significant for metabolites recovered in foliar-applied treated leaves. Flumioxazin metabolites in the treated leaf of four-leaf cotton totaled 4% of the applied ^{14}C 72 HAT (Figure 8). Flumioxazin metabolites in the treated leaf of 12-leaf cotton totaled 35% of the applied ^{14}C 72 HAT. All metabolites detected were more polar than flumioxazin. Because stem-applied flumioxazin is transported to leaves (7% at 72 HAT), these data suggest it could be metabolized within the leaf. Because the purity of the applied ^{14}C-flumioxazin was 94.2%, it is possible that the metabolites detected were present as contaminants within the applied solution; however, samples spiked with ^{14}C-flumioxazin did not result in metabolites having increased peak area (data not shown).

In summary, these data suggest that differential absorption and translocation at various growth stages, and to a lesser extent increased metabolism by more mature cotton plants contribute to differential tolerance of cotton receiving flumioxazin as a PDS at different growth stages. Differential absorption, not translocation or metabolism, was found to be the basis for soybean tolerance to root-absorbed sulfentrazone during the earliest stages of development (Li et al. 2000). However, postemergence-applied acifluorfen tolerance in eastern black nightshade (*Solanum ptycanthum* L.) has been shown to be due to differential metabolism compared to susceptible somaclones (Yu and Masiunas 1992). In cases where injury is observed on young cotton chlorophyllous green stem tissue following flumioxazin applied as a PDS, injury likely results from localized high concentrations of flumioxazin on the treated stem area due to lower levels of translocation out of the stem region compared to older cotton. Further, in older cotton plants with a bark layer on the lower stem, less localized injury was observed due to woody outer layers of bark tissue and more rapid translocation of herbicide out of the treated stem area to areas where it may be metabolized. Also, lower concentrations in the treated stem due to the greater biomass of an older cotton plant, continued absorption of applied flumioxazin into the stem from the treated stem surface, and limited subsequent translocation and potential metabolism may dilute flumioxazin concentration. These cumulative factors may contribute to reducing observed localized injury in older cotton.

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Table 1. Distribution of ^{14}C in cotton treated at 4-, 8-, and 12-leaf stage and harvested at 4, 24, 48, and 72 hours (h) after treatment. Means are percent of applied ^{14}C recovered in each tissue.

	4-leaf cotton				8-leaf cotton				12-leaf cotton			
	4 h[b]	24 h	48 h	72 h	4 h	24 h	48 h	72 h	4 h	24 h	48 h	72 h
Tissue	% of applied ^{14}C											
TS[a]	33 a[c]	41 a	53 a	56 a	31 b	47 ab	54 ab	57 a	33 a	48 bc	52 ab	53 a
ML	1 ghi	4 cde	7 bc	11 b	3 efgh	8 c	7 cde	6 cd	6 efg	7 defg	8 defg	7 defg
ILB	1 i	1 hi	3 def	3 efgh	2 h	1 I	3 gh	3 fgh	1 jk	1 jk	1 kl	3 ij
US	2 efgh	2 efg	6 bc	6 bcd	2 gh	3 fgh	3 defg	6 cd	6 efgh	4 fghi	4 fghi	11 defg
R	2 efgh	1 efgh	1 fghi	1 hi	2 gh	5 cdef	4 defg	4 defg	10 defg	13 def	22 cd	15 cde
FB	na	na	na	na	na	na	na	na	3 hij	4 fghi	5 fghi	4 ghi
S	na	na	na	na	na	na	na	na	1 jk	1 kl	1 l	1 kl
Non	61	51	30	23	60	36	29	24	40	22	7	6

[a] Abbreviations for plant parts and non-absorbed: TS, treated stem; ML, mature leaves; ILB, immature leaves and buds; US, untreated stem; R, roots; FB, fruiting branches; S, squares; Non, non-absorbed.

[b] Harvest timing represents hours after treatment.

Table 1. continued

[c] Each leaf stage was separated using Fisher’s Protected LSD on log-transformed data. Means followed by the same letter within each leaf stage are not significantly different.

Table 2. Distribution of ^{14}C in cotton treated at 4-leaf stage and harvested at 4, 24, 48, and 72 hours after treatment (HAT).

	4 HAT		24 HAT		48 HAT		72 HAT	
Tissue	Bq ^{14}C /gram dry wt.							
Treated stem	7,200	a[a]	7,343	a	9,095	a	6,344	a
Mature leaf	26	h	55	fgh	103	def	39	h
Immature leaves/buds	45	h	75	gef	1,048	bc	389	def
Untreated stem	137	cde	190	bcde	458	b	254	bcd
Roots	178	cde	151	cde	83	efg	43	gh
Fruiting branches	na		na		na		na	
Squares	na		na		na		na	

[a] Leaf stage was separated using Fisher's Protected LSD on log-transformed data. Means followed by the same letter are not significantly different.

Table 3. Distribution of ^{14}C in cotton treated at eight-leaf stage and harvested at 4, 24, 48, and 72 hours after treatment (HAT).

Tissue	4 HAT		24 HAT		48 HAT		72 HAT	
	—— Bq ^{14}C /gram dry wt.——							
Treated stem	3,445	a[a]	5,351	a	3,542	a	6,801	a
Mature leaf	402	cde	1,180	b	967	bc	775	bcd
Immature leaves/buds	252	e	153	f	459	de	364	de
Untreated stem	299	e	401	de	463	cde	871	bc
Roots	296	e	736	bce	472	cde	514	cde
Fruiting branches	na		na		na		na	
Squares	na		na		na		na	

[a] Leaf stage was separated using Fisher's Protected LSD on log-transformed data. Means followed by the same letter are not significantly different.

Table 4. Distribution of ^{14}C in cotton treated at 12-leaf stage and harvested at 4, 24, 48, and 72 hours after treatment (HAT).

	4 HAT		24 HAT		48 HAT		72 HAT	
Tissue	Bq ^{14}C /gram dry wt.							
Treated stem	1,124	hijk[a]	3,834	abc	3,029	ab	5,049	a
Mature leaf	398	defghi	554	def	1,650	de	538	def
Immature leaves/buds	146	ijkl	110	jkl	83	kl	326	fghij
Untreated stem	580	defg	377	defgh	333	defghi	907	de
Roots	585	hijk	1,060	de	1,454	cd	1,146	bcd
Fruiting branches	185	ghijk	296	efghij	454	defghi	339	defghi
Squares	181	defg	63	kl	44	defghi	682	hijk

[a] Leaf stage was separated using Fisher's Protected LSD on log-transformed data. Means followed by the same letter are not significantly different.

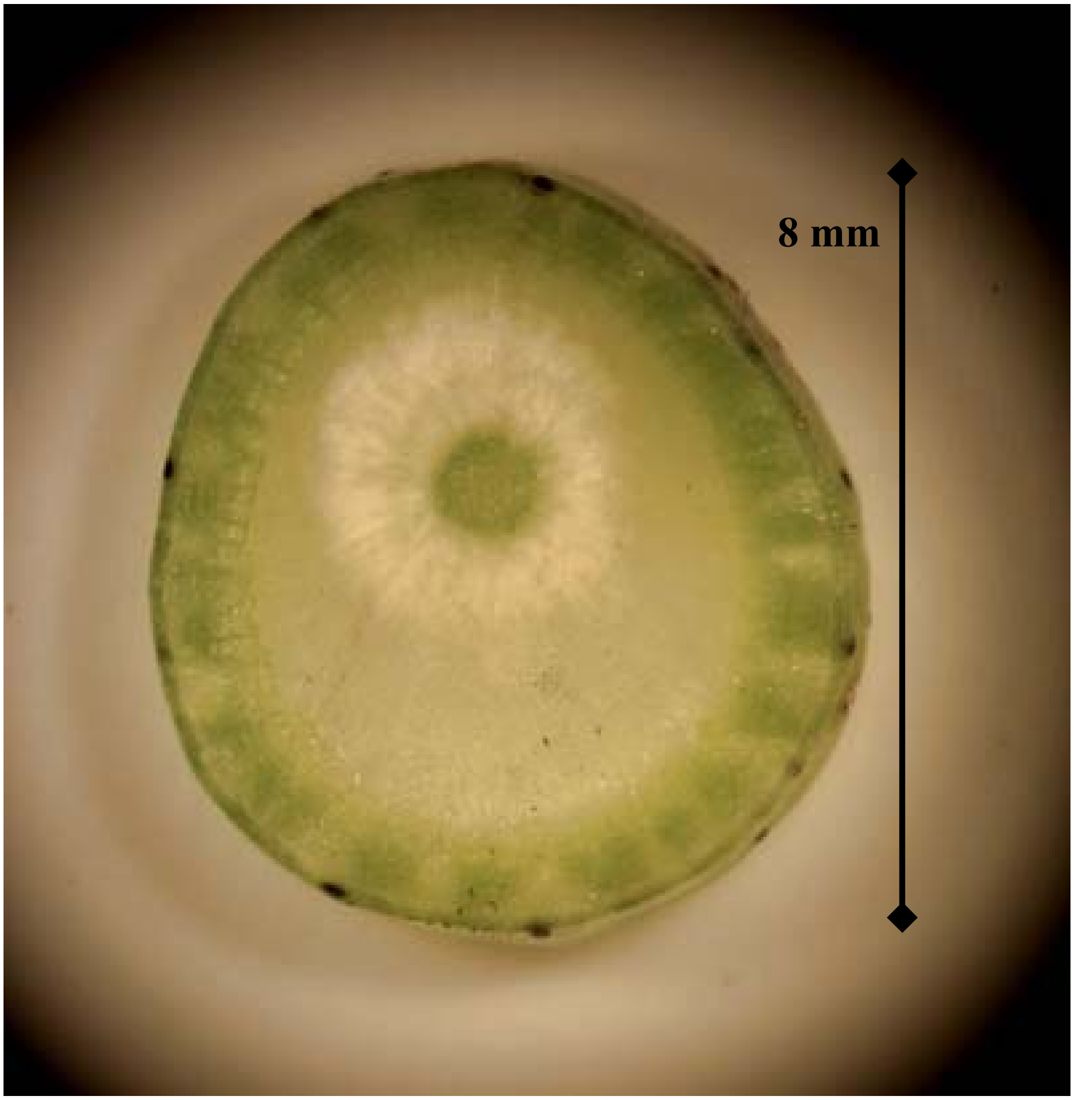

Figure 1. Untreated 5-leaf cotton stem (1.67X).

Figure 2. 5-leaf cotton stem treated with flumioxazin applied as a PDS at 0.071 kg ai/ha plus 0.25% v/v NIS (3.5X).

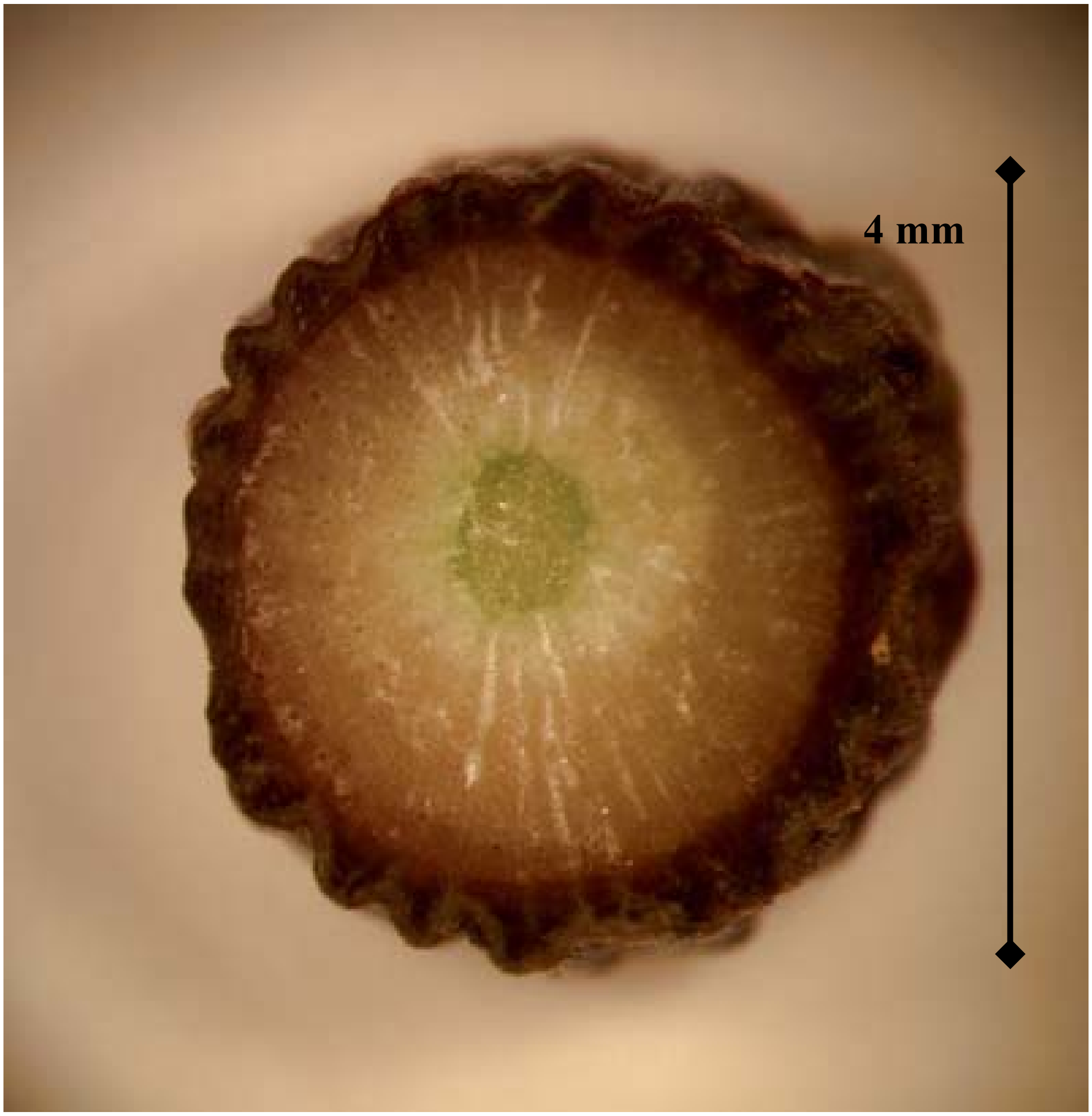

Figure 3. 5-leaf cotton stem treated with flumioxazin applied as a PDS at 0.071 kg ai/ha plus 1.0% v/v COC (3.5X).

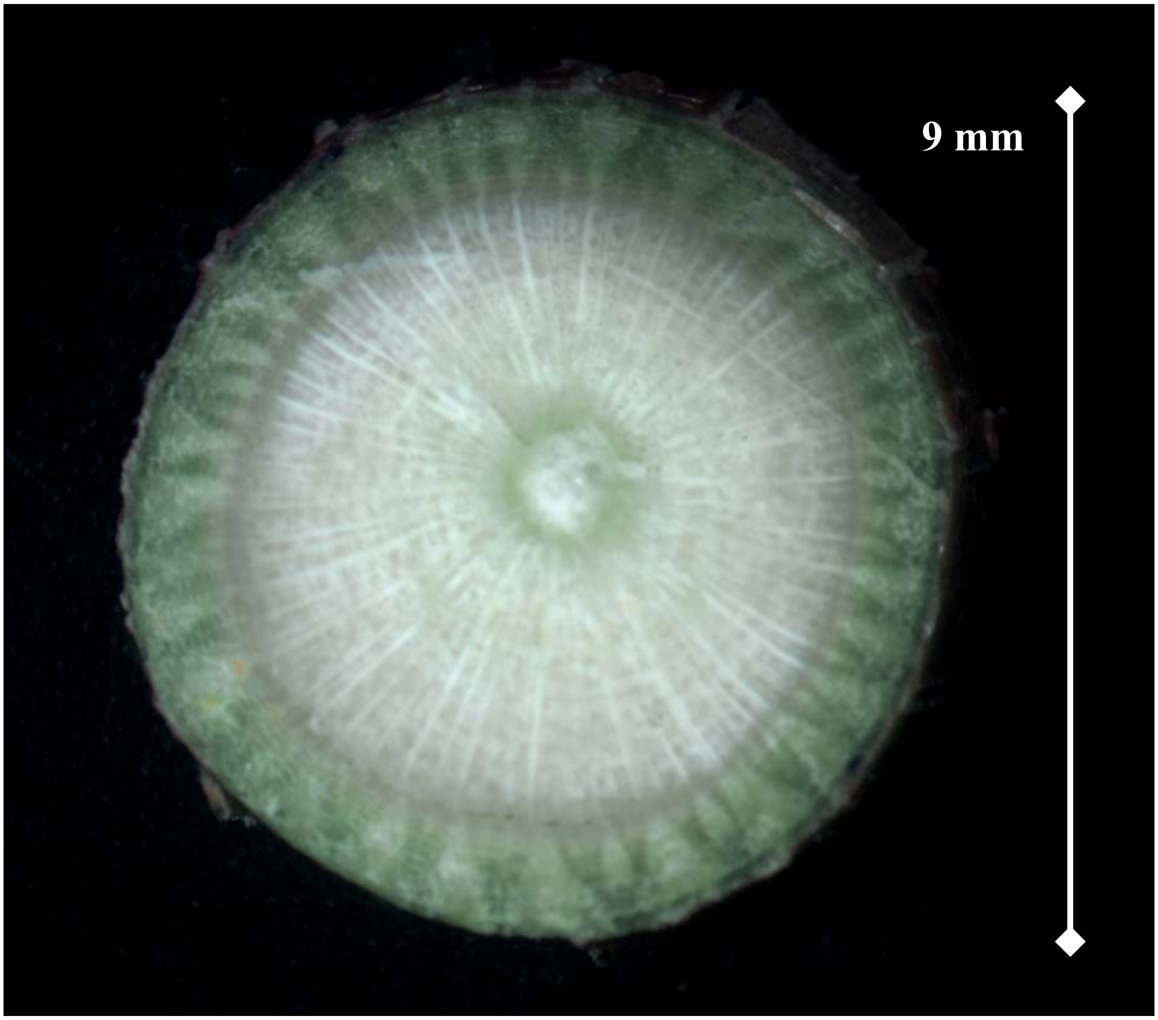

Figure 4. Untreated 16-leaf cotton stem (1.67X).

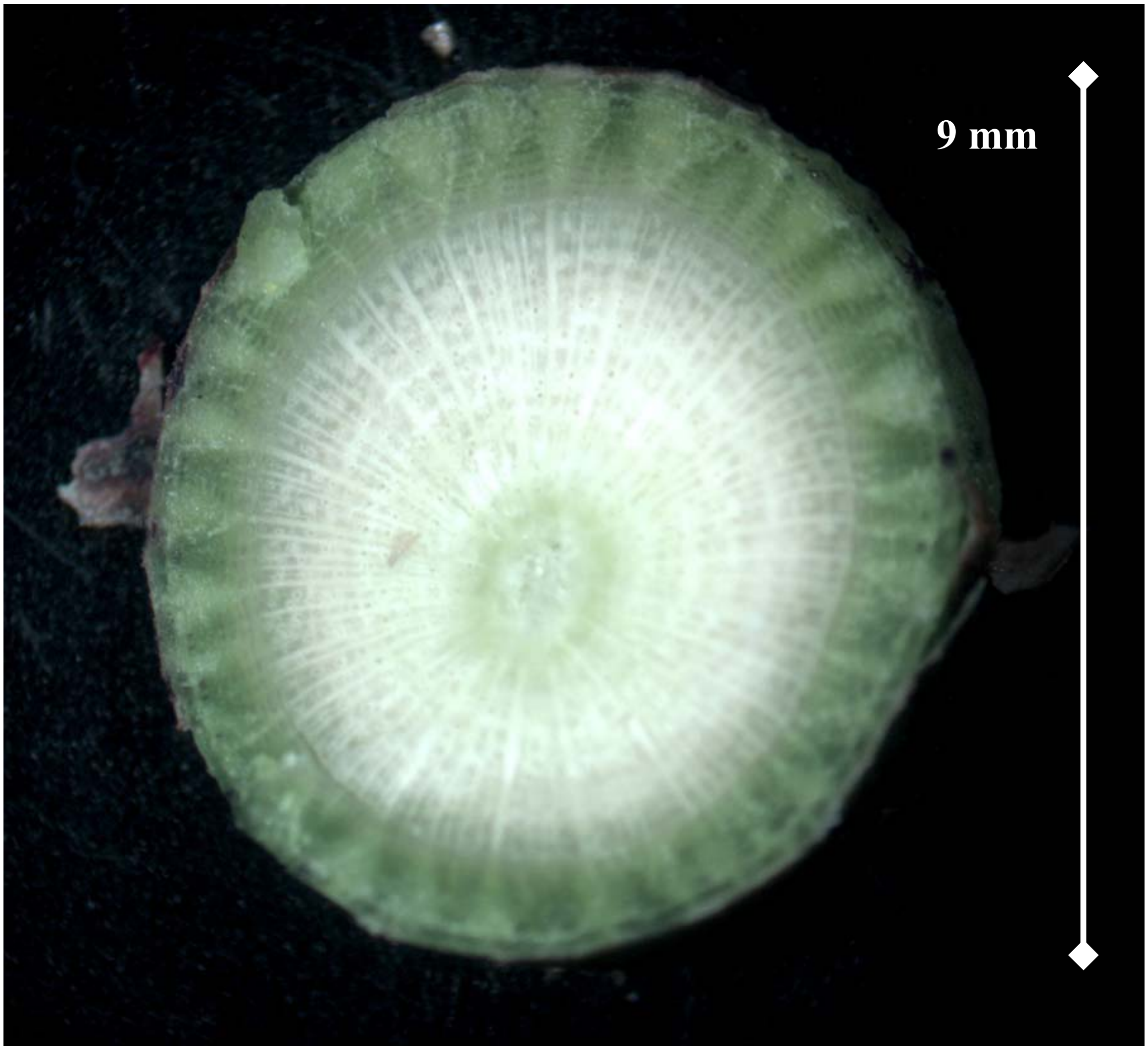

Figure 5. 16-leaf cotton stem treated with flumioxazin applied as a PDS at 0.071 kg ai/ha plus 0.25% v/v NIS (3.5X).

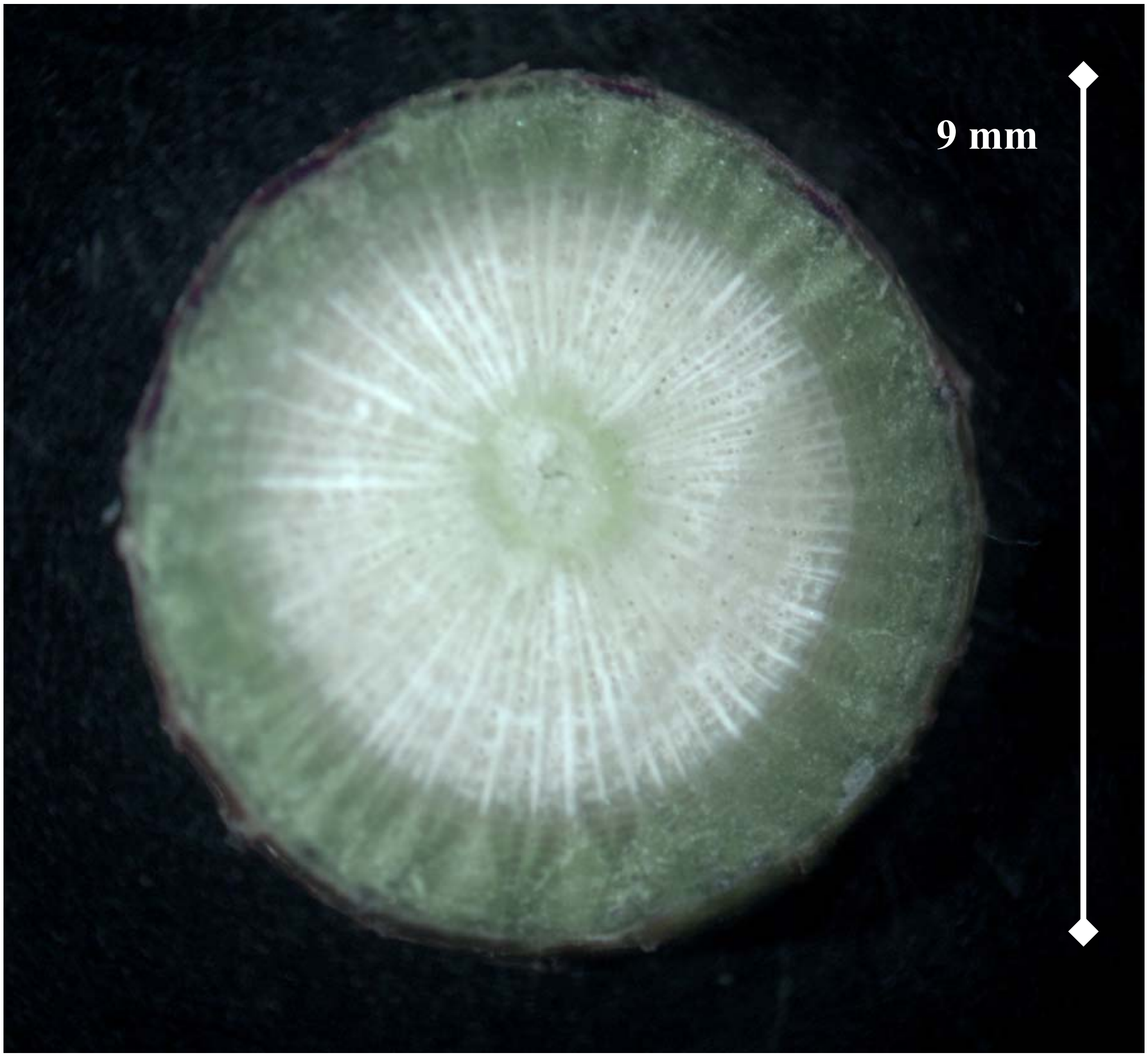

Figure 6. 16-leaf cotton stem treated with flumioxazin applied as a PDS at 0.071 kg ai/ha plus 1.0% v/v COC (3.5X).

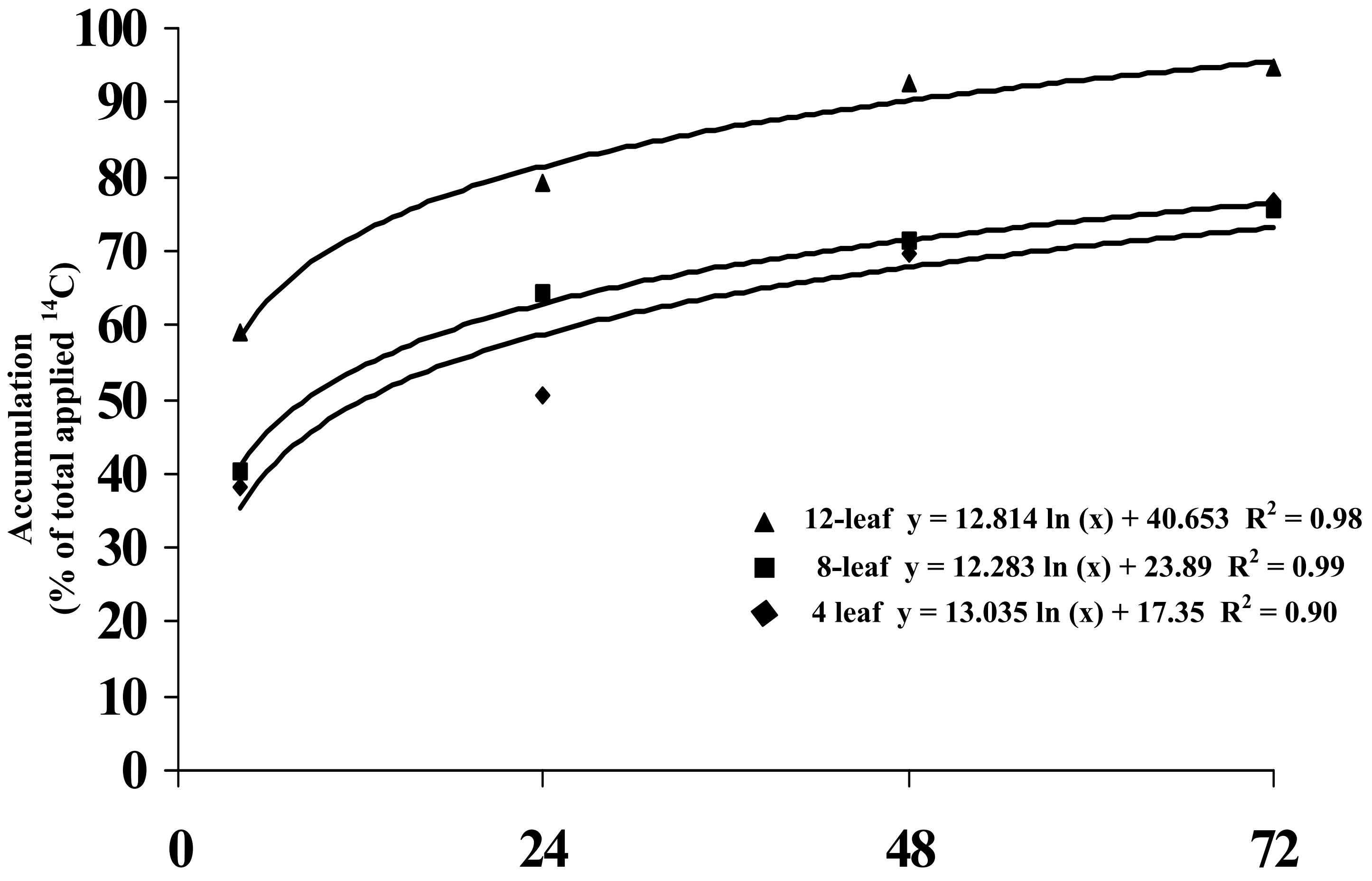

Figure7. Accumulation of ^{14}C in 4, 8, and 12-leaf cotton.

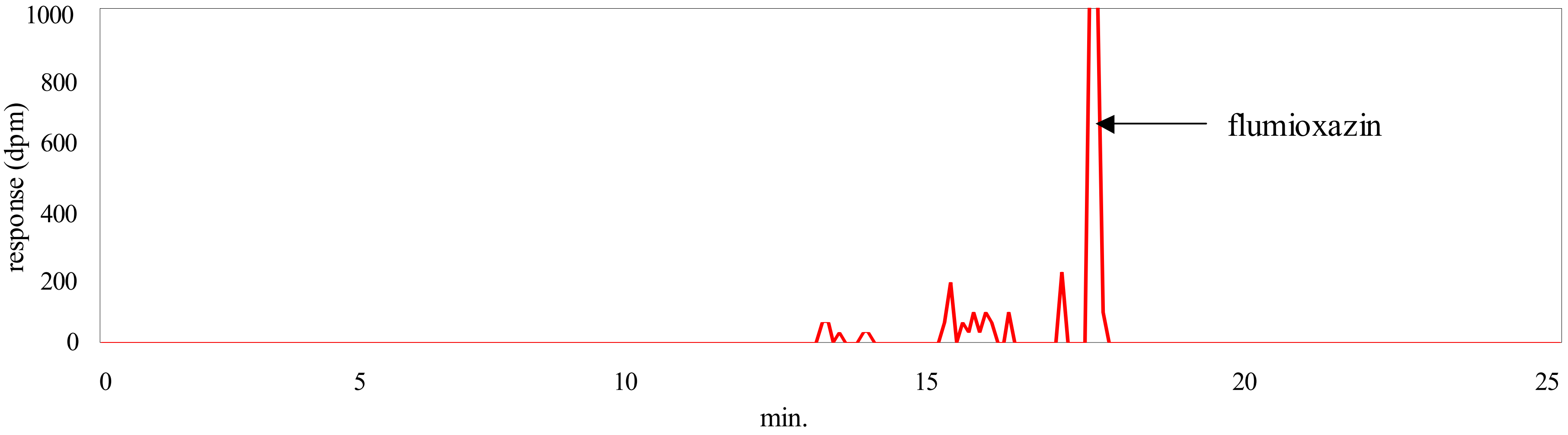

Figure 8. Chromatogram of parent flumioxazin and potential metobolites in 12-leaf cotton 72 HAT.

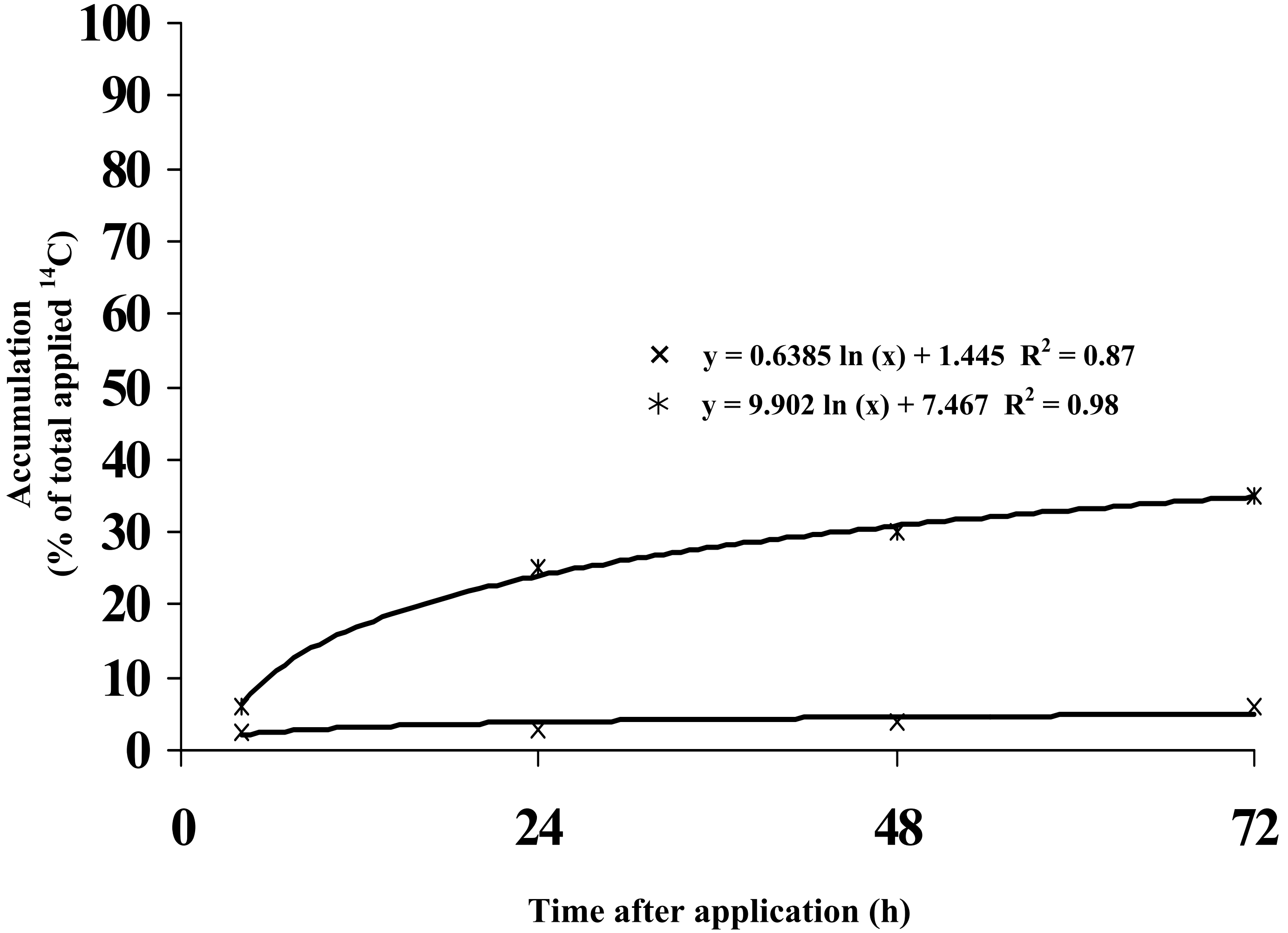

Figure 9. Accumulation of possible metabolites in 4 and 12-leaf cotton from foliar applied ^{14}C-flumioxazin.

Chapter 5

Various Flumioxazin PP or PDS Application Timings followed by Irrigation at Emergence or after PDS Treatment Does Not Influence Cotton (*Gossypium hirsutum* L.) Yield

Abstract: Three experiments were conducted in Lewiston, NC in 1999 through 2002 to determine the influence of timings of flumioxazin preplant (PP) and postemergence-directed (PDS) on cotton. In experiment one, flumioxazin was evaluated in a reduced-tillage system at 71, 105, or 140 g ai/ha with glyphosate, applied at 28, 14, or 7 d before planting (DBP), followed by irrigation at cotton emergence. Cotton treated PP with flumioxazin at any rate and irrigated at emergence injured cotton < 7% at 2 wks after emergence (WAE) and < 6% 5 WAE. In experiment two, flumioxazin was evaluated in a conventional-tillage system at 71 or 105 g/ha as a PDS treatment applied to dry soil, wet soil, and dry soil irrigated immediately after application when cotton was 20 to 30 cm height. Cotton treated with flumioxazin PDS at either rate applied to dry soil, wet soil, or dry soil followed immediately by irrigation was not injured. In the third experiment, flumioxazin at 71 g/ha alone or with glyphosate at 1.12 g/ha was applied at 30, 21, 14, and 0 DBP in a conventional-tillage system. Cotton treated with flumioxazin alone or in mixture with glyphosate applied at any time did not injure cotton. In all experiments, cotton lint yields were not influenced by herbicide treatment.

Nomenclature: cotton, *Gossypium hirsutum* L., ‘Deltapine 5415 BGRR’, ‘Paymaster 1218 RRBG’, ‘Surgrow 125’.

Additional index words: Burndown treatment, LAYBY treatment.

Abbreviations: DBP, days before planting; PRE, preemergence; PP, preplant; POST, postemergence; PDS, postemergence-directed spray; PPI, preplant incorporated; WAE, weeks after emergence.

Introduction

Common preplant (PP) burndown treatments in cotton include paraquat and glyphosate (Brown and Whitwell 1985; Price and Wilcut 2002; White and Worsham 1990; York 1995). Both herbicides provide inexpensive winter cover burndown and broad-spectrum weed control (Wilcut et al. 1995). Unfortunately, neither herbicide effectively controls all weeds and they do not provide residual weed control (Price and Wilcut 2002). Approximately 35 to 40% of North Carolina cotton hectarage does not receive soil-applied herbicide treatments at planting and reduced tillage production is increasing (A. C. York, personal communication). The exclusion of residual preemergence (PRE) herbicides at planting allows early-season weed interference which may be detrimental to cotton yield (Askew and Wilcut 1999; Buchanan and Burns 1970; Clewis et al. 2000; Culpepper and York 1998; Price and Wilcut 2002; Scott et al. 2001). A residual herbicide applied PP in mixture with relatively non-selective herbicides like glyphosate or paraquat could allow flexibility of POST application timings while minimizing early-season weed competition (Price and Wilcut 2002).

Glyphosate-resistant cotton cultivars are planted on greater than 75% of the North Carolina cotton hectarage and similar percentages are planted in other cotton producing states (A. C. York, K. L. Edminsten, NC State University, personal communication). As glyphosate label restrictions do not allow over-the-top applications of glyphosate on greater than 4-leaf cotton, most cotton growers in the southeast utilize postemergence-directed spray (PDS) applications (Anonymous 1999). At the time this research was initiated, the most common herbicides applied PDS in cotton include cyanazine, fluometuron, MSMA, and prometryn (Byrd 1999; Wilcut and Askew 1999; Wilcut et al. 1995).

Flumioxazin is a *N*-phenylphthalimide herbicide registered PRE in peanut (*Arachis hypogaea* L.) and as an early-PP burndown treatment in cotton (Anonymous 2002; Askew et al. 1999; Burke et al. 2002; Clewis et al. 2002; Grichar and Colburn 1996). Previous research indicated that flumioxazin may be applied PP or PDS in cotton (Askew et al. 2002; Cranmer et al. 2000; Main et al. 2000). Cotton injury from flumioxazin PP may occur and is influenced by application timing in respect to planting (Askew et al. 2002). Cotton injury due to flumioxazin PDS treatments has the potential to injure cotton less than 30 cm tall if the herbicide contacts green stem material due to rain splash or misapplication (Altom et al. 2000; Wilcut et al. 2000). Thus, rainfall or precipitation when cotton seedlings are emerging could be of concern.

Flumioxazin PP or PDS controls common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), entireleaf morningglory (*Ipomoea hederacea* var. *integruiscula* L.), ivyleaf morningglory (*Ipomoea hederacea* L. Jacq.), Palmer amaranth (*Amaranthus palmeri* L.), pitted morningglory (*Ipomoea lacunosa* L.), prickly sida (*Sida spinosa* L.), smooth pigweed (*Amaranthus retroflexus* L.), and tall morningglory [*Ipomoea purpurea* (L.) Roth] (Askew et al. 2002; Clewis et al. 2002; Niekamp et al. 1999). Although flumioxazin may have potential as a PP or PDS alone or in mixture with various PP and PDS herbicides in cotton, the effects of rainfall at cotton emergence after flumioxazin PP treatment or the effects of rainfall before or soon after flumioxazin PDS application on cotton are unknown. Therefore, field studies were conducted to determine 1) cotton response in a weed free environment to flumioxazin PP followed by irrigation at crop emergence, 2) cotton response in a weed free environment to flumioxazin PDS applied to dry soil, wet soil, or dry soil followed by irrigation immediately after application, and 3) cotton response in a weed free environment to flumioxazin plus glyphosate PP tank mixture.

Materials and Methods

Field experiments were conducted at the Peanut Belt Research Station located near Lewiston-Woodville, NC in 1999 through 2002. Soils were a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudults) with 1.0 to 1.1% organic matter and pH 5.7 to 5.9.

Preplant Irrigation Experiment. The PP irrigation study was conducted in 2000 and 2001 and treatments were arranged in a four by three factorial design of flumioxazin rate and PP application timing with three replications of treatment. Flumioxazin treatments applied to a stale seedbed included flumioxazin at 0, 71, 105, or 140 g ai/ha in mixture with glyphosate at 0 or 1.12 kg ai/ha applied at 28, 14, or 7 days before planting (DBP). Cotton 'Deltapine 5415 BGRR' was planted into corn residue on May 16, 2000 and 'Paymaster 1218 BGRR' was planted into peanut residue on May 15, 2001. A crop oil concentrate[1] (COC) at 1.67% (v/v) was included with all flumioxazin-containing PP treatments. All plots were broadcast-treated with a compressed CO_2 backpack sprayer delivering 140 L/ha spray solutuion at 147 kPa. Cotton seeds were planted at 13 to 20 seeds per meter of row using a conventional planter (Edmisten 2002). Plots consisted of four rows 92 cm wide and 9.1 m long.

Land preparation for planting included opening the soil with the subsoiler shank of a Ro-Till® planter with the planter units removed to open the soil and destroy plow pans beneath

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[1] Agridex®, 83% paraffin base petroleum oil and 17% surfactant blend. Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN 38137.

the rows 4 wk prior to planting. Fluted coulters attached to the planter smoothed the soil and broke up large clods. Rolling crumblers that were mounted immediately behind the fluted coulters served to further smooth the seedbed. Approximately 60% of the surface residue remained in the tilled area and 90 to 95% of the non-tilled area was covered with residue after seedbed preparation.

At cotton emergence, 2.5 cm of water was applied to all plots with a lateral movement overhead irrigation system. When cotton reached the 4-leaf growth stage (26 to 28 d after planting), glyphosate was applied over-the-top at 1.12 kg/ha to control emerged weeds in all plots. This treatment is standard for weed management in glyphosate-resistant cotton in North Carolina and according to the glyphosate label (Anonymous 1999; Culpepper and York 1998; Scott et al. 2001). A late PDS application of prometryn at 1.12 kg ai/ha plus MSMA at 2.24 kg ai/ha plus 0.25% (v/v) NIS[4] and hand weeding as needed were used to keep plots weed free. This approach allowed evaluation of early-season cotton injury from PP treatments and to ascertain weed free crop response from PP treatments.

Postemergence-directed Spray Irrigation Experiment. For the PDS irrigation study conducted in 1999 and 2000, the experimental area was conventionally prepared, then treated with trifluralin PPI at 0.94 kg ai/ha, fluometuron PRE at 1.12 kg ai/ha plus pyrithiobac PRE at 0.036 kg ai/ha, followed by pyrithiobac at 0.07 kg/ha POST. Pyrithiobac POST treatments included 0.25% (v/v) non-ionic surfactant[2] (NIS). Cotton 'Suregrow 125' was planted on May 5,1999 and May 10, 2000. Cotton seeding rate and plot size were as previously

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[2] Induce® nonionic low foam wetter/spreader adjuvant containing 90% nonionic surfactant (alkylarylopolyoxyalkane ether and isopropanol), free fatty acids, and 10% water. Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN 38137.

mentioned. Postemergence-directed spray treatments applied in factorial treatment arrangement included 1) flumioxazin at 0, 71, or 105 g/ha, 2) cyanazine at 0 or 0.84 kg ai/ha, or 3) prometryn at 0 or 1.12 kg ai/ha were applied to dry soil, moist soil, or dry soil that was immediately irrigated after treatment with 2.5 cm of water as previously described. Treatments were replicated three times. A NIS at 0.25% (v/v) was included with all cyanazine, flumioxazin, and prometeryn-containing treatments. Postemergence-directed spray treatments were applied in 20 to 30 cm cotton in 1999 and 2000. Treatments were applied with a backpack sprayer as previously described.

Flumioxazin plus glyphosate PP application timing study. The third experiment was conducted in 2001 and 2002. Treatment combinations reflected a three by four factorial treatment arrangement of PP treatment and PP application timing with three replications of treatment. Preplant treatments applied to a seedbed at 30, 21, 14, and 0 DBP included 1) flumioxazin at 0 or 71 g/ha, 2) flumioxazin at 71 g/ha in mixture with glyphosate at 1.12 g/ha, or 3) glyphosate at 0 or 1.12 g/ha. A COC at 1.67% (v/v) was included with all flumioxazin-containing treatments. Land was prepared for planting as described in the first experiment. Cotton ‘Paymaster 1218 BGRR’ was planted into peanut residue on May 15, 2001 and cotton residue April 15, 2002. Cotton seeding rate and plot size were as previously described. Treatments were applied with a backpack sprayer as previously described.

Cotton was evaluated for PP treatment injury 2 and 5 wks after emergence (WAE) and for PDS treatment injury 2 and 5 wks after treatment. Cotton injury, based on visual leaf discoloration, visual stunting, and visual stand reductions were estimated on a scale of 0 (no injury symptoms) to 100 (complete death of all plants or no plants present) (Frans et al.

1986). The center two rows of each plot were harvested once for lint and seed with a spindle picker modified for small-plot harvesting.

Data in all experiments were subjected to analysis of variance (ANOVA) using the general linear models procedure in SAS (SAS 1998) to evaluate the effect of each factorial herbicide treatment arrangement. Herbicide treatments were considered fixed effects while year, location, and year by location effects were considered random variables. Non-transformed data for visual evaluations are presented because arcsine square root transformation did not affect data interpretation. Means for appropriate main effects and interactions were separated using Fisher's protected LSD test at P = 0.05. Data were combined where interactions did not occur; data were presented separately when interactions occured.

Results and Discussion

Preplant Irrigation Experiment. *Cotton injury*. There was a treatment by year interaction for cotton injury; therefore, data are presented by year. In 2000 at early-evaluation (2 WAE), flumioxazin treatments at 71 or 105 g/ha applied at 28 or 14 DBP or glyphosate applied at 7 DBP did not injure cotton (Table 1). All other treatments injured cotton 3% or less. By 5 WAE, no visible injury was observed on cotton treated with flumioxazin (any rate) at 28 DBP or glyphosate applied at 7 DBP. Flumioxazin applied at 105 g/ha 7 DBP injured cotton 6%. All other treatments injured cotton 1 to 3%. In 2001, injury at 2 and 5 WAE was 7% or 6% or less, respectively. In 2000, plots received 1.7 cm of rain between treatments applied at 28 and 14 DBP with no other precipitation occurring until after irrigation. In 2001, 3.2 cm of precipitation occurred between 28 and 14 DBP treatments. Additionally, 0.3 cm occurred between 14 and 7 DBP treatments and also between 7 DPB treatments and planting. In 2001, injury would have likely been greater if no rain was received between flumioxazin application and irrigation treatment. Observed flumioxazin PP injury to cotton was comparable to injury levels reported by both Askew et al. (2002) and Price and Wilcut (2002). Although injury may occur when flumioxazin is applied PP, the levels of injury observed in this study are not likely to be of agronomic importance. Fluometuron PRE has been widely used in North Carolina for over two decades and early season cotton injury of 15% is not uncommon (A. C. York, personal communication). Cotton is reported to recover from less than 25% early-season injury and avoid yield loss (Chandler and Savage 1980; Hayes et al. 1981; Walsh et al. 1993).

Cotton yield. Treatments as well as the year by treatment interaction for cotton lint yield were not significant (P > 0.05); therefore, treatments were combined for presentation. However, there was a significant year main effect for cotton yield; consequently, yields are presented separately by year. Yields averaged 1,650 kg/ha in 2001 and 1,980 kg/ha in 2002 (Table 2). A typical cotton yield without seed for North Carolina is around 800 kg/ha (North Carolina Dept. of Agriculture Statistics 1998-2000). Yields in these studies are likely due to the optimal growth conditions resulting from keeping plots weed free and irrigated production. These studies agree with previous research that reported cotton yields were not influenced by flumioxazin at 71 g/ha PP when applied between 0 and 10 wks prior to planting (Askew et al. 2002).

Postemergence-directed Spray Irrigation Experiment. *Cotton injury.* Treatments as well as the year by treatment interaction for cotton injury were not significant; therefore, data were combined (P > 0.05). In 1999 and 2000, no cotton stem injury or rain splash injury was observed at either evaluation (data not shown). These results differ from those observed in previous research. Intense rainfall encountered in thunderstorms may have caused reported injury in previously reported research (Altom et al. 2000; Wilcut et al. 2000). The water droplet size and intensity generated by the lateral movement overhead irrigation system used in this experiment would likely be less than the intensity in a thunderstorm. The lack of rain splash injury may be due to other reasons including differing soil texture or extent of canopy closure of these studies compared to those previously reported. Also, cotton injured by the PDS application in the study reported by Wilcut et al. (2000) was 15 cm or less in height compared to cotton 20 to 30 cm in height in this study. Previous research showed that flumioxazin PDS injury on the cotton stem was related to cotton growth stage and that once cotton gained a bark layer on the lower stem, injury was reduced (Price and Wilcut 2002). The lack of injury on the cotton stem in this study is likely due to more precise PDS application and the presence of a bark layer on the more mature cotton in this experiment at time of application. Results from this and other experiments suggest that flumioxazin applied PDS at 71 g/ha would be safe for use in irrigated and non-irrigated cotton if cotton was at least 20 cm in height and had developed a bark layer on lower stem. However, rain splash from intense thunderstorms may have the potential to injure cotton.

Cotton yield. The influence of herbicide treatment as well as the year by treatment interaction for cotton lint yields were not significant ($P > 0.05$); therefore, treatments were combined for presentation. However, there was a significant year main effect for cotton yield; consequently, yield are presented separately by year. Yields averaged 1,480 kg/ha in 1999 and 1,820 kg/ha in 2000 (Table 3).

Flumioxazin plus Glyposate PP Application Timing Experiment. *Cotton injury.* Treatments as well as the year by treatment interaction for cotton injury were not significant; therefore, data were combined ($P > 0.05$). Little to no cotton injury was observed at either evaluation in either year (data not shown). Observed cotton injury to flumioxazin PP were less than injury levels reported by Askew et al. (2002) and Price et al. (2002).

Cotton yield. Treatments as well as the year by treatment interaction for cotton lint yield were not significant ($P > 0.05$); therefore, treatments were combined for presentation. However, there was a significant year main effect for cotton yield; consequently, average yield are presented separately by year. Yields averaged 1,650 kg/ha in 2001 and 640 kg/ha in 2002 (Table 4). Low yield was attained in 2002 due to drought.

These data suggest that flumioxazin is a safe herbicide for use in cotton as a PP 7 DBP on similar soils if rainfall occurs between herbicide application and planting. These data also support flumioxazin PP labels for PP application at 71 g/ha at least 30 d before planting cotton if 2.54 cm of rainfall or irrigation occurs before planting (Anonymous 2002a; 2002b). The inclusion of a residual herbicide such as flumioxazin in a PP treatment should reduce early season weed interference in production systems that do not use herbicides or tillage at planting to control emerged vegetation. Because many reduced-tillage systems plant glyphosate-resistant cultivars in North Carolina, flumioxazin PP in a tank mixture with a non-selective herbicide like glyphosate or paraquat may reduce the density of problematic winter annuals weeds found in reduce-tillage and glyphosate-resistant cotton systems (Price and Wilcut 2002). These data also suggest that flumioxazin is a safe PDS herbicide on 20 to 30 cm tall cotton grown on similar to soil in this research when followed by irrigation or light rain. However, intense natural rainfall occurring after flumioxazin application and previous to a less intense precipitation event may have the potential to cause injury after flumioxazin applied PDS, and further investigation of this potential problem may be warranted.

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Table 1. Cotton injury 2 and 5 wks after emergence (WAE) from flumioxazin or glyphosate preplant treatment 28, 14, or 7 days before planting (DBP) in North Carolina.

		2000		2001	
Herbicide treatment	DBP	2 WAE	5 WAE	2 WAE	5 WAE
		% injury			
Flumioxazin 71 g/ha	28	0b[a]	0c	1b	1b
Flumioxazin 105 g/ha	28	0b	0c	2b	1b
Flumioxazin 140 g/ha	28	1a	0c	3b	2b
Glyphosate 1.12 kg/ha	28	1a	2b	0c	0c
Flumioxazin 71 g/ha	14	0b	1b	1b	1b
Flumioxazin 105 g/ha	14	0b	3b	2b	5a
Flumioxazin 140 g/ha	14	2a	3b	7a	4ab
Glyphosate 1.12 kg/ha	14	1a	1b	0c	1b
Flumioxazin 71 g/ha	7	3a	3b	1b	2b
Flumioxazin 105 g/ha	7	3a	6a	3b	4ab
Flumioxazin 140 g/ha	7	2a	3b	3b	6a
Glyphosate 1.12 kg/ha	7	0b	0c	1b	2b

Table 1. continued

[a] Injury was separated using Fisher's Protected LSD on non-transformed data. Means in a column followed by the same letter are not significantly different.

Table 2. Main effect of year on cotton seed lint yield in Lewiston, North Carolina for the preplant irrigation experiment.

Cotton yield[a]	
2000	2001
——kg/ha——	
1,650	1,980

[a]ANOVA indicated a significant year main effect ($P > 0.05$); therefore, yield data are presented by year.

Table 3. Main effect of year on cotton seed lint yield in Lewiston, North Carolina for the postemergence-directed spray irrigation experiment.

Cotton yield[a]	
1999	2000
——kg/ha——	
1,480	1,820

[a] ANOVA indicated a significant year main effect (P > 0.05); therefore, yield data are presented by year.

Table 4. Main effect of year on cotton seed lint yield in Lewiston, North Carolina for the flumioxazin plus glyposate PP application timing experiment.

Cotton yield[a]	
2001	2002
———kg/ha———	
1,330	640

[a] ANOVA indicated a significant year main effect ($P > 0.05$); therefore, yield data are presented by year.

CHAPTER 6

Response of Ivyleaf Morningglory [(*Ipomoea hederacea* (L.) Jacq.] to Neighboring Plants and Different Colored Painted Lumber

Abstract: Field observations of morningglory (*Ipomoea spp*.) found that many plants grew out of places of comparable competitive advantage (alleys in field experiments with little or no vegetation) onto neighboring plants or structures that allowed a climbing habitat. In a field survey, a total of 223 morningglory plants growing in rows and row middles in a 121 m^2 area within established corn research plots containing no other weeds revealed that of the total morningglory plants surveyed, 68% that were large enough climbed up corn plants. More significant, of the 152 climbing morningglory, 96% had grown to the row closest in proximity instead of growing across the row middle. Greenhouse and field research were initiated to determine if morningglory grew preferentially toward colored structure or green corn plants. Greenhouse-grown ivyleaf morningglory displayed varying frequency of positive growth response toward black (17%), blue (58%), green (75%), red (58%), yellow (67%), white (75%) stakes, or corn (92%). Pots containing black stakes had the fewest climbing morningglory. In the field study, fewer ivyleaf morningglory climbed black structures compared to white or green-colored structures or corn. The morningglories' planting distance from structures was also significant for percentage of ivyleaf morningglory that exhibited climbing growth as well as their final weight. Morningglory that successfully located and climbed structures had greater dry weights and produced more seed. Ivyleaf morningglory appear to respond to spatial distribution of surrounding objects and possibly

used reflectance to preferentially project their stems toward the most prospective structure for climbing.

Nomenclature: ivyleaf morningglory, [*Ipomoea hederacea* (L.) Jacq.] #[3] IPOHE; corn, *Zea mays* L..

Key words: light response, morningglory biology.

Introduction

Morningglory (*Ipomoea spp*.) are annual low climbing vines that grow up neighboring crop plants for support as they exhibit positive phototropism to intercept sunlight. Morningglory have been shown to have varying effects on crop yields depending on limiting resources such as light, nutrients, and water (Cordes and Bauman 1984; Holloway and Shaw 1996; Oliver et al. 1976). Morningglory can reduce harvested crop quality, and in moderate populations, they can reduce harvesting efficiency (Buchanan et al. 1980; Cordes and Buchanan 1984; Howe et al. 1987; Murdock et al. 1986). Morningglory can grow and reproduce readily on the ground surface; however, our field observations found that many morningglory appeared to grow preferentially toward upright (erect) plants or structures that provide support for a climbing growth habit.

Location of neighboring plants or objects may be due to a phototropic response, a basic growth-orienting process in which unilateral light plays a central role in orienting shoots of plants to grow asymmetrically. One mechanism of positive phototropic curvature or growth occurs when plants intercept light in the blue or green wavelength region (450 to 550 nm)

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

(Aphalo and Ballare 1995; Koller 1990; Iino 1990; Parsons et al. 1984; Steinitz et al. 1985). Subsequently an asymmetric distribution of auxin on the shaded side may lead to cell elongation and stem curvature toward the strongest sources of unilateral light (Kaufman et al. 1995).

Proximity of neighboring green vegetation on which morningglory could climb may also be detected due to the quality of light within the red and far-red wavelengths (600 to 800 nm) (Aphalo and Ballare 1995; Ballare et al. 1995; Britz and Galston 1983; Iino 1990; Koller 1990). This response mechanism utilizes phytochromes that detect light quality, specifically, the balance between red and far-red light. Ballare et al. (1995) showed that cucumber (*Cucumis sativus* L.) without pytochrome-B respond less to far-red light compared to wild types. Open canopies, such as the artificial light gaps created in corn in this study, have light containing a high red to far-red ratio. As a canopy closes due to increased plant height and width, the ratio of red to far-red decreases as distance to the ground decreases. In most plants, nearby vegetation would cause initiation of shade-avoidance reactions (Ballare et al. 1995; Iino 1990).

Research has shown that for field dodder (*Cuscuta planiflora* L.) exhibits or possesses a phototropic curvature that was induced toward regions of lowered red to far-red light (Orr et. al. 1996a). This response aids field dodder in host location and attachment. In another field dodder study, near vertical seedlings were grown in white light and then cyclically illuminated from above with red light for four hours, then red plus far-red light for four hours (Orr et. al. 1996b). Time-lapsed video showed that stems grew toward far-red light and away from red light. Spectral distributions, red to far-red ratios, and phytochrome equilibria have been measured in canopies composed of *Brassica spp*. or tobacco (*Nicotiana tabacum* L.)

plants (Smith et. al. 1990). Measurements were taken for radiation traveling vertically downward and radiation traveling horizontally. Radiation near the canopy was shown to be depleted in the 400 to 690 nm wavelength range while increased in the 690 to 800 nm wavelength range. Smith et al. (1990) hypothesize that the detection of spectral quality by the phytochrome would allow for the detection and determining proximity of neighboring plants even when not being shaded by its neighbor(s). Results also showed that lowered red to far-red radiation produced by a 12 cm high *Brassica spp*. was detected by a spectroradiometer up to 30 cm away, and up to 45 cm away from a 30 cm high tobacco stand. In a controlled soybean [*Glycine max* (L.) Merr.] experiment, plants exposed to five minutes of far-red light at the end of each day had longer internodes and fewer branches than plants not exposed to far-red light (Kasperbaur 1987). Dry matter partitioning in this field study was also related to red to far-red light ratios.

We are not aware of any published literature concerning responses of *Ipomoea* morningglory to neighboring plants and objects. Based on field observations, morningglory appear to preferentially grow towards structures that reflect regions of more intense reflected solar radiation or altered light quality. Characterizing morningglories climbing response would allow for a better determination of distance of spectral influence and potential for interference. Therefore, studies were initiated to investigate the response of morningglory to neighboring corn plants and different colored structures.

Methods and Materials

Field Survey. All morningglory growing within two separate established corn trials infested with only isolated morningglory were characterized as exhibiting climbing or non-climbing habit. Row spacing for corn was 92 cm. For morningglory climbing corn, the distance from the emergence site of the morningglory plant to the corn plant was recorded. For non-climbing morningglory plants, the distance from the apical meristem to nearest corn plant was recorded. In each case, morningglory species were also identified. Data were subjected ANOVA to determine if trial effects were significant. Then, both chi-square analysis and Fisher's exact tests were used to determine significance of presence or absence of climbing growth habit as well as possible species effects on climbing habit.

Greenhouse experiment plant material and growth conditions. Experiments were conducted in a glass greenhouse maintained at approximately 25 ± 2 C with a 16 h day-period of natural lighting with an average midday photosynthetic flux density of 700 μmol $m^{-2}s^{-1}$. Two completely randomized experiments were conducted using three replications of treatment. Treatments were 30 cm corn plants or six different 30 cm tall colored stakes. Stake colors were non-flat black[4], non-flat bright red[4], non-flat light blue[4], non-flat light yellow[4], non-flat medium green[4], and non-flat white[4]. Four ivyleaf morningglory seed were sown opposite stakes or corn plants, and upon emergence thinned to one universal size plant per pot. Pots were watered daily taking care not to physically disturb morningglories. The experiments were conducted in 15 L black pots containing 10 cm of Metro-Mix 360[5]. This method created an environment in which the morningglory received direct sunlight for approximately 2.5 h and received reflected light off the colored stakes or corn for the remainder of day. This method also shielded morningglory from reflected color from neighboring pots. Morningglory plants were characterized as exhibiting climbing or non-

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[4] Premium Spray Enamel Paint. Orgill, Inc. Memphis, TN 38101.

[5] Metro-Mix 360, Scotts-Sierra Horticulture Products Co., 14111 Scottslawn Rd., Marysville, OH 43041

climbing habit on stakes or corn plants at daily intervals after emergence. Reflected solar radiation spectral quality of each stake was measured using a LICOR 1800 spectroradiometer[6] measuring every 2 nm, from 200 nm to 1200 nm, and averaged over five consecutive measurements. Red (600 to 699 nm) to far-red (700 to 800 nm) ratios were also calculated. Data were subjected to ANOVA and means separated using Fisher's protected LSD at the 5% probability level.

Field Experiment. The field experiment consisted of a split-split plot design with randomized plots and three replications of treatment. The main plot factor was structure consisting of 4.5 by 9.5 by 244 cm lumber painted black[7], green[7], or white[7], or 183 cm corn. The first subplot factor was planting distance from either a corn plant or painted structure within a plot. Planting distances were 15, 30, 61, 91, or 122 cm. The second subplot factor was east or west orientation of morningglory planting location to the corn plant or painted structure. The experiment was conducted twice. Corn was established and the painted structure was placed in the field when the corn reached mature height (184 cm). The structure was placed 60 cm in the ground and oriented with the 9.5 cm side east/west. Ivyleaf morningglory were seeded and thinned to one uniform plant upon emergence. Corn and morningglory were watered as needed with care taken not to physically disturb either plant. Plots were kept weed free by hand weeding with similar care. If morningglory grew within 5 cm of structure, a trellis system extending 3 cm out from surface on which the morningglory could climb was erected utilizing 5 cm drywall screws and nylon twine. At the

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[6] LI-COR Biosciences Inc. 4308 Progressive Avenue, PO Box 4000, Lincoln, NB 68504.

[7] Glidden America's Finest Outdoor Exterior Semi-gloss Paint. The Glidden Co. Cleveland, OH 44115.

experiments termination, morningglory's habit was characterized as climbing or non-climbing. Morningglory had produced seed and were beginning to senesce at experiment termination. For non-climbers, distances from apical meristems to corn or structure were recorded. At final harvest, all morningglories' total dry above ground biomass and total seed production was determined. Reflected solar radiation for each stake color was taken early in the season as previously described and was initiated at when sun was at solar noon. Blue and green absorbance maximums were tested for correlation of intensity of reflected light at these wavelengths with percentage of morningglory successfully locating and climbing structure and corn. Also, red (600 to 699 nm) to far-red (700 to 800 nm) ratios were calculated and tested for correlation with percentage of morningglory successfully locating and climbing structure and corn.

Data were subjected to ANOVA with sums of squares partitioned to reflect a split-split-plot treatment structure and trial effects. The three different colored structure and corn were considered main plots, the two planting orientations were considered subplots, and the six initial planting distances were considered sub-subplots. Residuals were plotted, and logarithmic transformations conducted on data where variance increased with increasing means. Following ANOVA, treatment or log transformed treatment means were compared using Fisher's Protected LSD test at the 5% probability level. Where main effects were significant, regressions were used to explain the relationship of measured response over time.

Results and Discussion

Field Survey. ANOVA indicated no differences of the percentage of morningglory that climbed corn between the two trials surveyed, thus data are combined for presentation. Also, there was no difference in response among morningglory species; therefore, data were combined across species for presentation. A total of 223 morningglory consisting of entireleaf morningglory (*Ipomoea hederacea* var. *integriscula* Grey), ivyleaf morningglory, pitted morningglory (*Ipomoea lacunosa* L.), and tall morningglory (*Ipomoea purpurea* L. Roth) were characterized. Out of the 223 morningglory characterized, a significant majority, 152 or 68% of the total number of morningglory that were large enough to locate the corn and climbed, had done so successfully. More notably, of the 152 that exhibited climbing habit, a significant majority (96%) grew to the row closest to the point of morningglory emergence.

Greenhouse Study. ANOVA indicated there was no treatment by experimental run interaction; therefore, experiments were combined for presentation. The red to far-red ratios for the colored stakes were as follows: black, 0.70; blue, 0.78; green, 0.93; red, 1.5; white, 1.2; yellow, 1.1 and corn, 0.51 (data not shown). The white stake had the greatest total reflected photon flux density compared to all other stakes and the black stake had the least (Figure 1). Greenhouse grown morningglory displayed varying degrees of positive growth response toward green corn and all colored stakes. The frequency of climbing of the 12 morningglory plants observed for each treatment were as follows: black (17%), blue (58%), green (75%), red (58%), white (67%), yellow (75%) stakes, or corn (92%) (Table 1). The treatment consisting of the black stake had fewer morningglory recording a yes response to climbing habit. There was no correlation between red to far-red ratio and the frequency of morningglory climbing habit.

Field Study. There was no treatment by location interaction; therefore, experiments were combined for presentation. Reflected blue light had an absorbance maximum of 480 nm and reflected green light had an absorbance maximum of 528 nm for all structures at all initial distances (Figures 2, 3, 4, and 5). White structures reflected more blue light at 15 and 30 cm planting distances than did any other treatment and also at 61 cm planting distance compared to black or green structure (Table 2). Morningglory grown in plots containing white or green structures or corn at 15 or 30 cm planting distance received more reflected green light than morningglory grown in plots containing black structure (Table 2). At 61 cm planting distance, morningglory grown in plots containing white structures or green corn received more green light than did morningglory grown in plots containing green or black structures. However, differences in blue or green light due not appear to influence morningglory growth habit.

There was no difference in red to far-red ratios between planting distances for plots containing green (0.78) and black (0.87) colored structures (Table 3). Planting distances for green corn had red to far-red ratios of 0.50, 0.58, 0.61, 0.72, and 0.82 for the respective initial distances of 15, 30, 61, 91 and 122 cm. These data show that morningglory grown in plots with green corn were subjected to more far-red light at 15 and 30 cm initial distances than morningglory grown in plots containing any other colored structures and at 61 cm compared to green and black colored structures. The white colored structures treatment had red to far-red ratios of 1.55, 1.12, 1.00, 0.98, and 0.96 for the respective initial distances of 15, 30, 61, 91 and 122 cm. However, there was no correlation between red to far-red ratio and morningglory climbing response. The white structures reflected more red light at 15, 30, and 61 cm planting distances and had the greatest total reflected photon flux density at all wavelengths at all initial distances compared to black or green structures or green corn (Figures 2, 3, 4, and 5). The green structures had higher total reflected photon flux density at all initial distances compared to black structures.

The main plot factor structure was significant for climbing growth, with fewer morningglory climbing black structures compared to white or green colored structures or corn (Figure 6). The subplot factor planting distance was also significant for percentage of morningglory that climbed (Figure 7). Morningglory planted within 46 cm of white or green structures or corn located and climbed ≥ 78% of the time. Morningglory planted within 46 cm of black structures located and climbed ≤ 21% of the time. As planting distance increased, the number of morningglory that successfully located and climbed all colored structures and corn decreased. Morningglory were observed to initiate stem branching as early as 8-leaf growth stage (data not shown). Also, at three weeks after planting, morningglory that had not located and climbed structure or corn tended to branch more than those that were growing toward structure or corn (data not shown).

The main plot factor was also significant for morningglory above ground biomass, with morningglory plants in the plots containing black structures weighing less (Figure 8). This result likely reflects that morningglory that successfully located and climbed structure weighed more than those that remained on the ground. The planting distance was also significant for morningglory final weight, decreasing weight with increasing planting distance, likely reflecting decreasing climbing habit with increasing planting distance (Figure 9). Increased morningglory dry weight as a result of climbing increased production of seed with increasing seed production with increasing weight (Figure 10).

Ivyleaf morningglory tend to respond to spatial distribution of surrounding objects and apparently responded by preferentially projecting their stems toward the most prospective regions for climbing. However, due to lack of correlation between red to far-red ratios and the percentage of morningglory that successfully located and climbed structure, phototropism due to red to far-red light ratio is unlikely to be the mechanism by which morningglory growth responds. Also, intensity of blue and green light was not correlated to the percentage of morningglory that successfully located and climbed structure. Further research is necessary to elucidate mechanisms triggering preferential growth exhibited by morningglory. These data show that if morningglory that germinate within 46 cm of green corn, 78% of the time they will successfully locate and climb. Because many crops are planted with row spacing of 76 to 90 cm, the success of morningglory to locate and climb a crop readily illustrates reasons why control of *Ipomoea* morningglories is critical. Also, these data show that as morningglory successfully locate and climb structure, seed production increases.

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Table 1. Frequency of greenhouse grown ivyleaf morningglory that successfully located and climbed stakes and corn.

Treatment	Frequency
	%
Black stake	17
Blue stake	58
Green corn	92
Green stake	75
Red stake	58
White stake	67
Yellow stake	75
LSD[a]	34

[a] Means were separated using Fisher’s Protected LSD on non-transformed data.

Table 2. Photon flux densities at 480 nm (blue absorbance maximum) and 528 nm (green absorbance maximum) for white, green, or black colored structure and green corn located in the field.

		Initial distance (cm)					
		15	30	61	91	122	
Treatment	Wavelength (nm)	Photon flux density					LSD[a]
		μmol $m^{-2}s^{-2}$					
White structure	480	0.41	0.28	0.20	0.18	0.16	0.04
Green structure	480	0.11	0.10	0.09	0.09	0.09	0.03
Black structure	480	0.08	0.08	0.07	0.06	0.05	0.03
Green corn	480	0.14	0.14	0.14	0.14	0.13	0.03
LSD[a]		0.07	0.06	0.08	0.08	0.09	
White structure	528	0.41	0.27	0.20	0.18	0.15	0.04
Green structure	528	0.17	0.13	0.11	0.10	0.10	0.03
Black structure	528	0.08	0.07	0.07	0.06	0.05	0.03
Green corn	528	0.20	0.19	0.17	0.15	0.14	0.03
LSD[a]		0.08	0.06	0.08	0.09	0.11	

[a] Means were separated using Fisher's Protected LSD on non-transformed data.

Table 3. Red to far-red ratios for white, green, and black colored structure and green corn located in the field.

	Initial distance (cm)					
	15	30	61	91	122	
Treatment	Photon flux density					LSD[a]
	——————μmol $m^{-2}s^{-2}$——————					
White structure	1.55	1.12	1.0	0.98	0.96	0.13
Green structure	0.79	0.78	0.79	0.78	0.78	0.11
Black structure	0.86	0.88	0.87	0.88	0.87	0.10
Green corn	0.50	0.58	0.61	0.72	0.82	0.11
LSD[a]	0.23	0.27	0.18	0.25	0.26	

[a] Means were separated using Fisher's Protected LSD on non-transformed data.

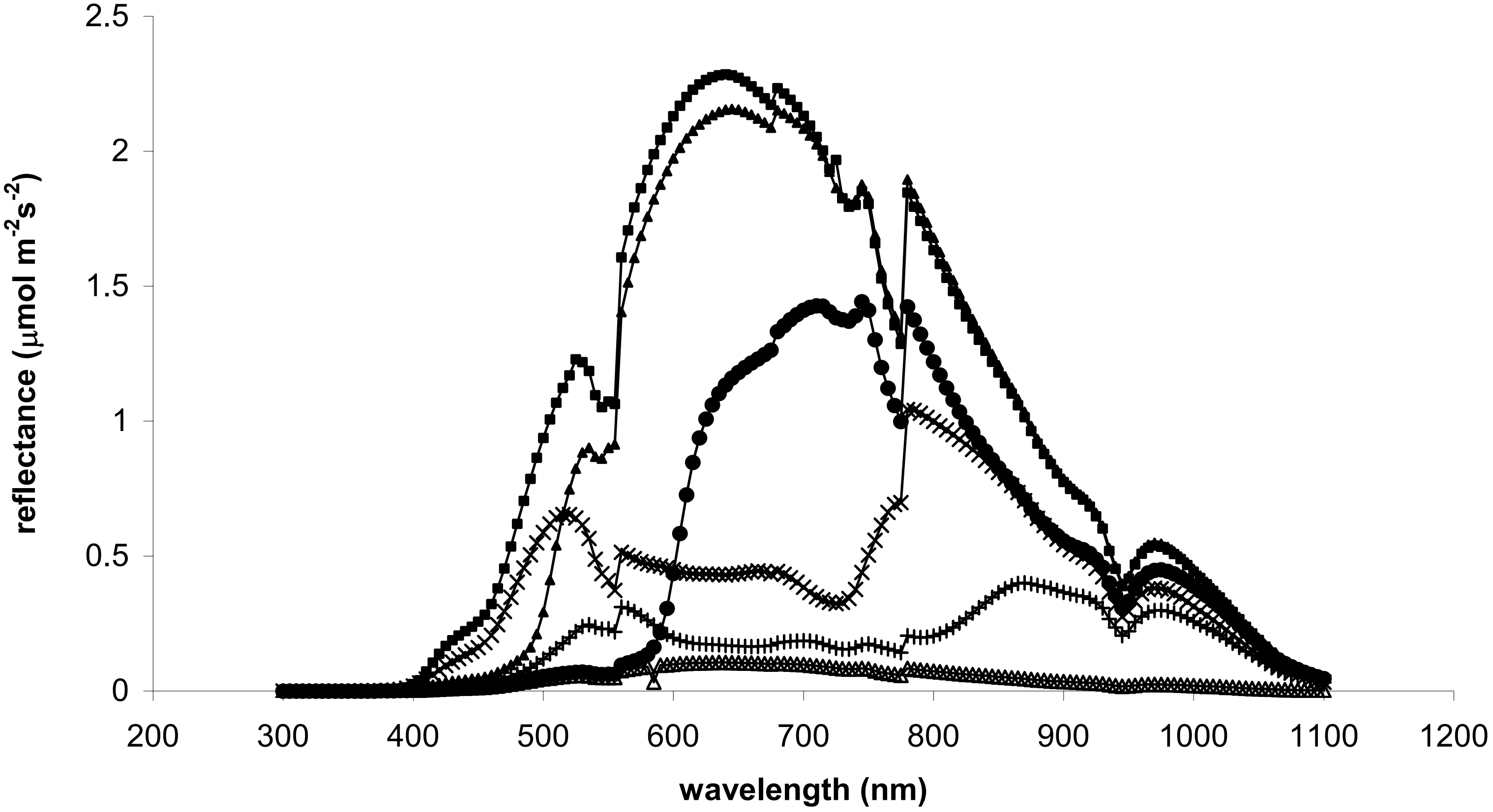


Figure 1. Reflected spectra of stakes in greenhouse study for white (■),yellow (▲), red (•), blue (×), green (+), and black (△) stakes at 15 cm.

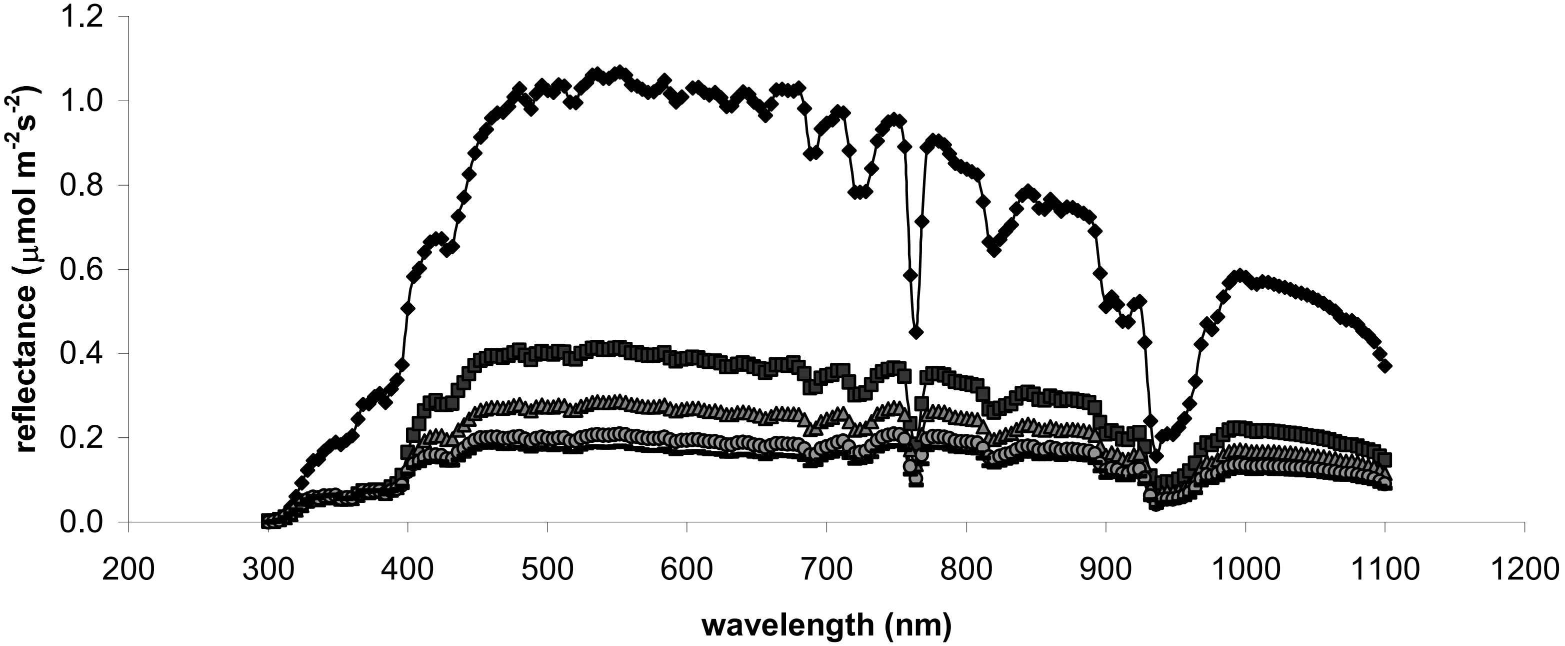


Figure 2. Re Reflected spectra of white structure in field study at 15 cm (◆), 30 cm (■), 61 cm (▲), 91 cm (•), and 122 (_) cm initial morningglory seeding distances.

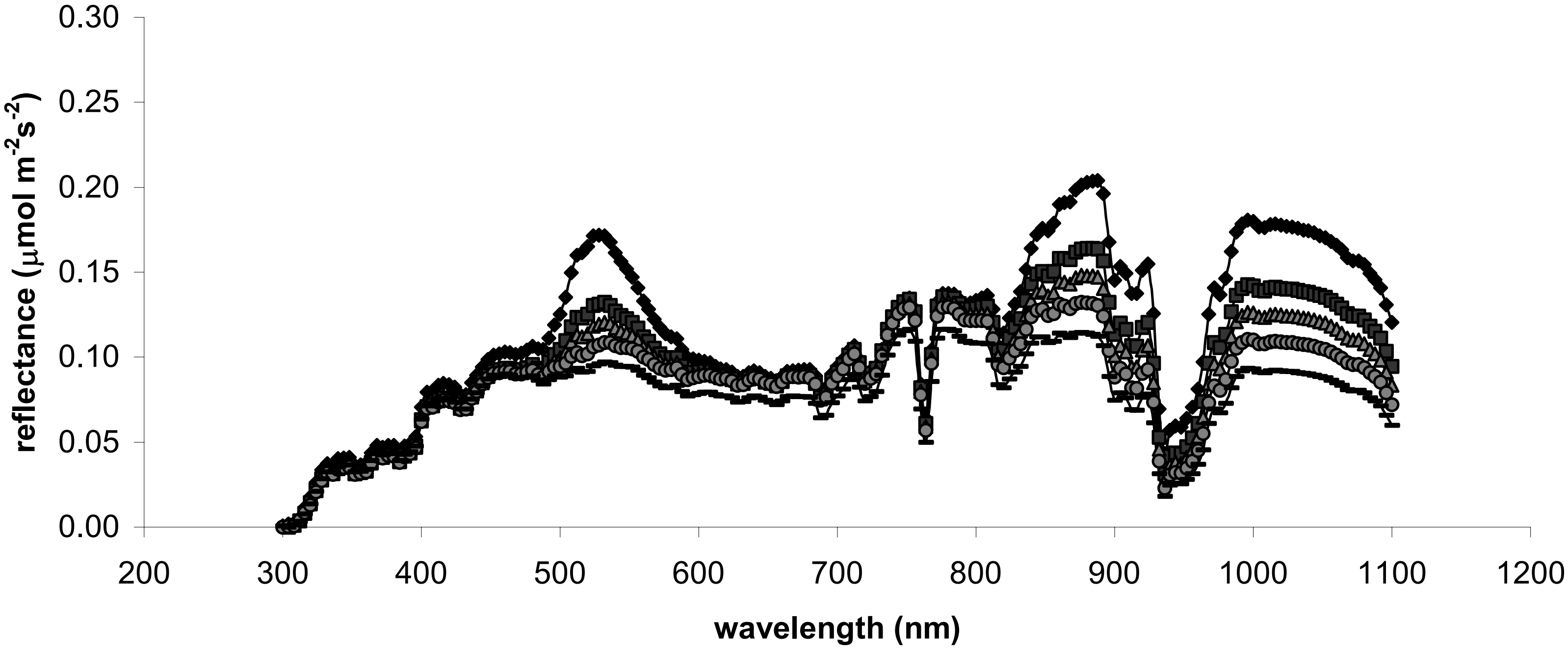


Figure 3. Reflected spectra of green structure in field study at 15 cm (◆), 30 cm (■), 61 cm (▲), 91 cm (•), and 122 (▬) cm initial morningglory seeding distances.

1

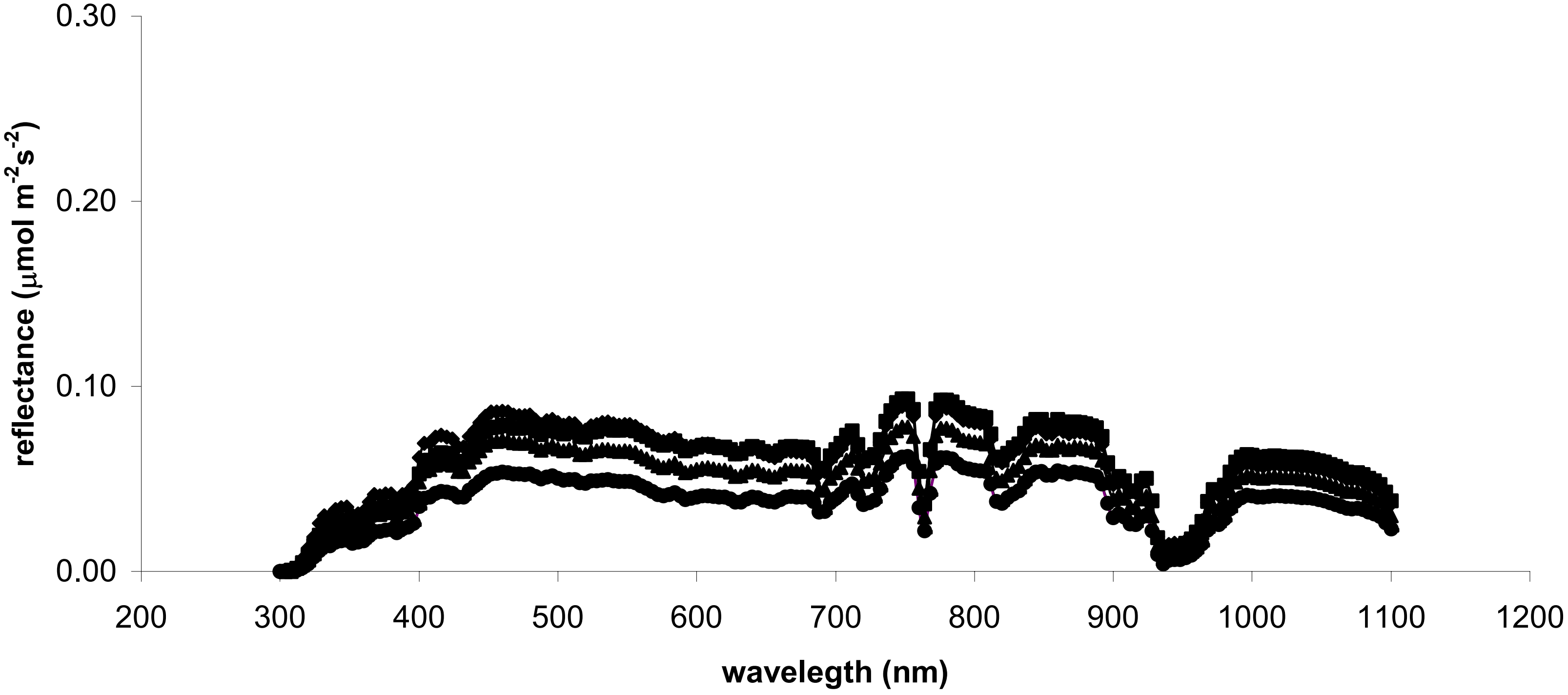
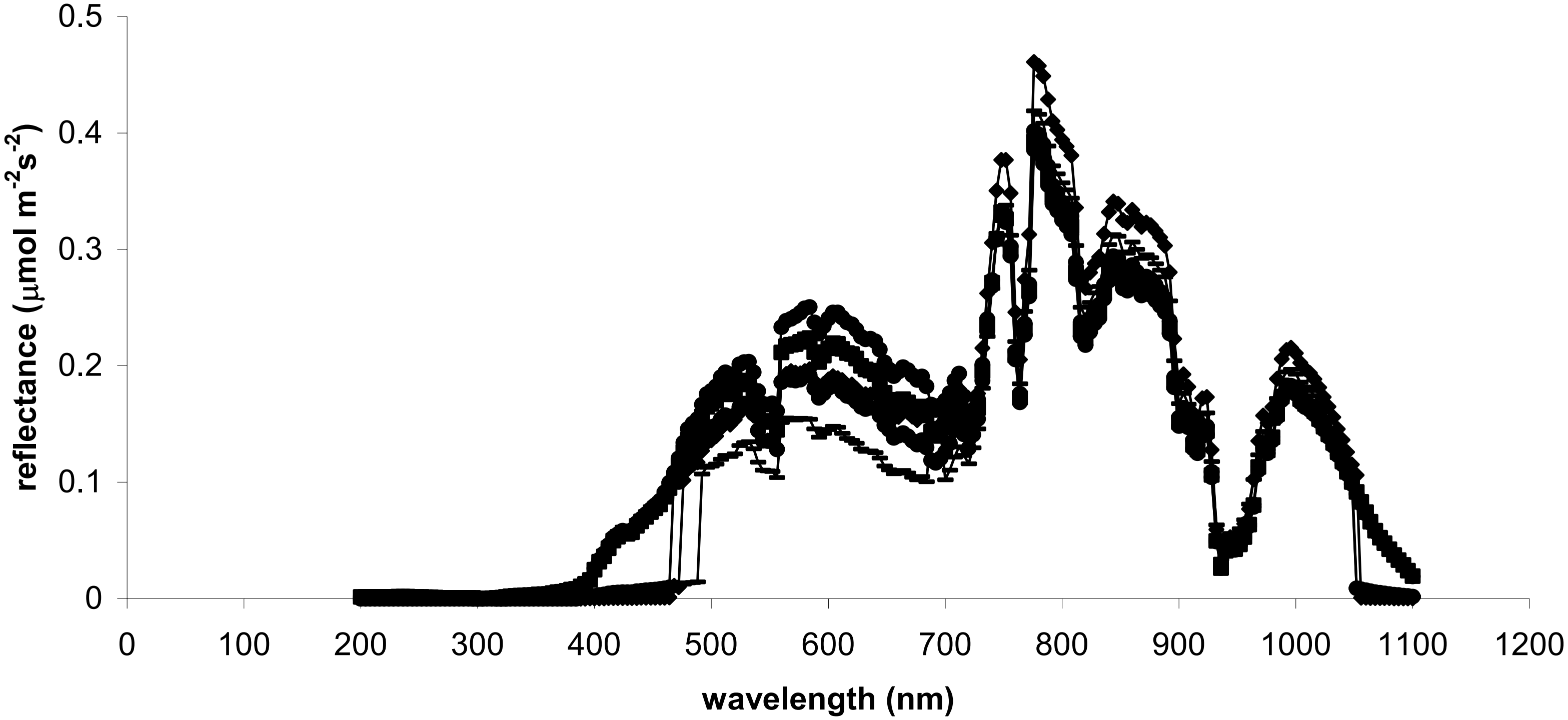


Figure 4. Reflected spectra of black structure in field study at 15 cm (◆), 30 cm (■), 61 cm (▲), 91 cm (•), and 122 (‒) cm initial morningglory seeding distances.



1

Figure 5. Reflected spectra of green corn in field study at 15 cm (◆), 30 cm (■), 61 cm (▲), 91 cm (•), and 122 (‗) cm initial morningglory seeding distances.

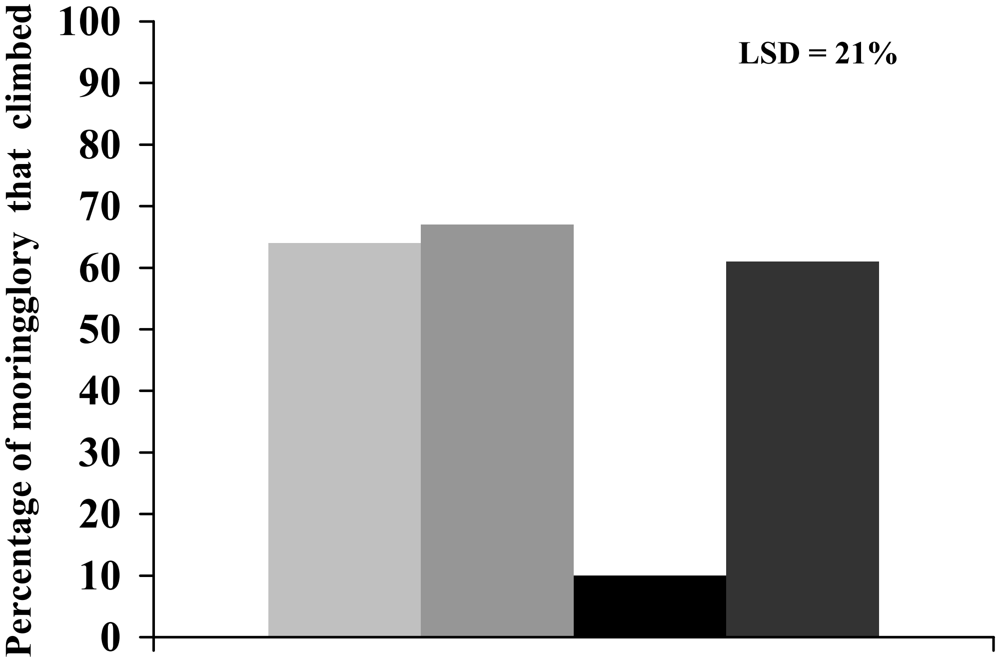
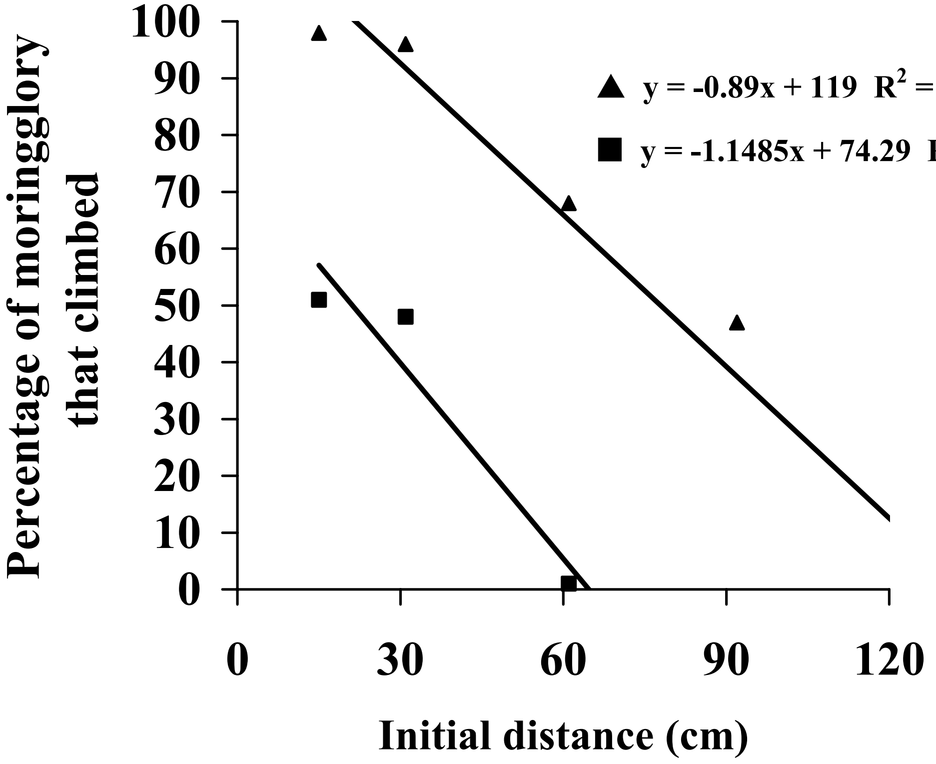


Figure 6. Percentage of morningglory in field study that successfully located and climbed white (■), green (■), and black (■) structure or corn (■).



<u>Figure 7</u>. Percentage of morningglory in field study that successfully located and climbed black structure (■), or white and green structures and corn (▲) as influenced by initial distance.

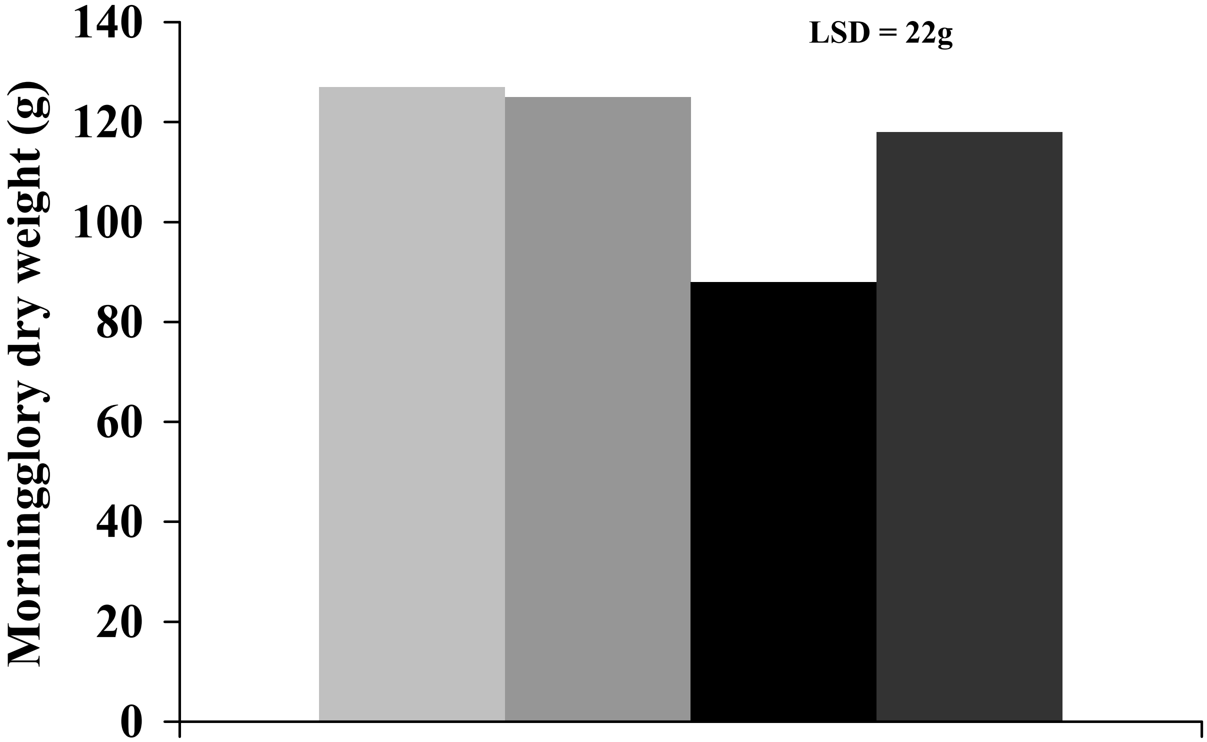


Figure 8. Average dry weight for morningglory in field study grown in plots containing white (■), green (■), and black (■) structure or corn (■).

1

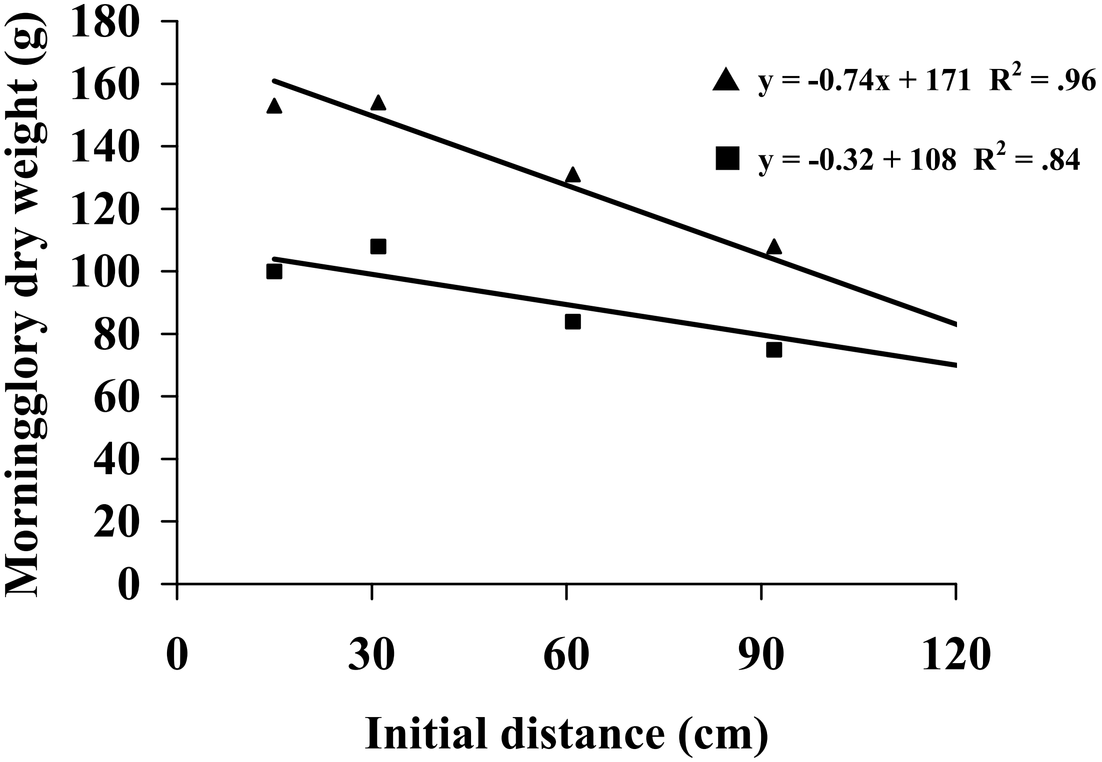


Figure 9. Average morningglory dry weight in field study for black structure (■), or white and green structures and corn (▲) as influenced by initial distance.

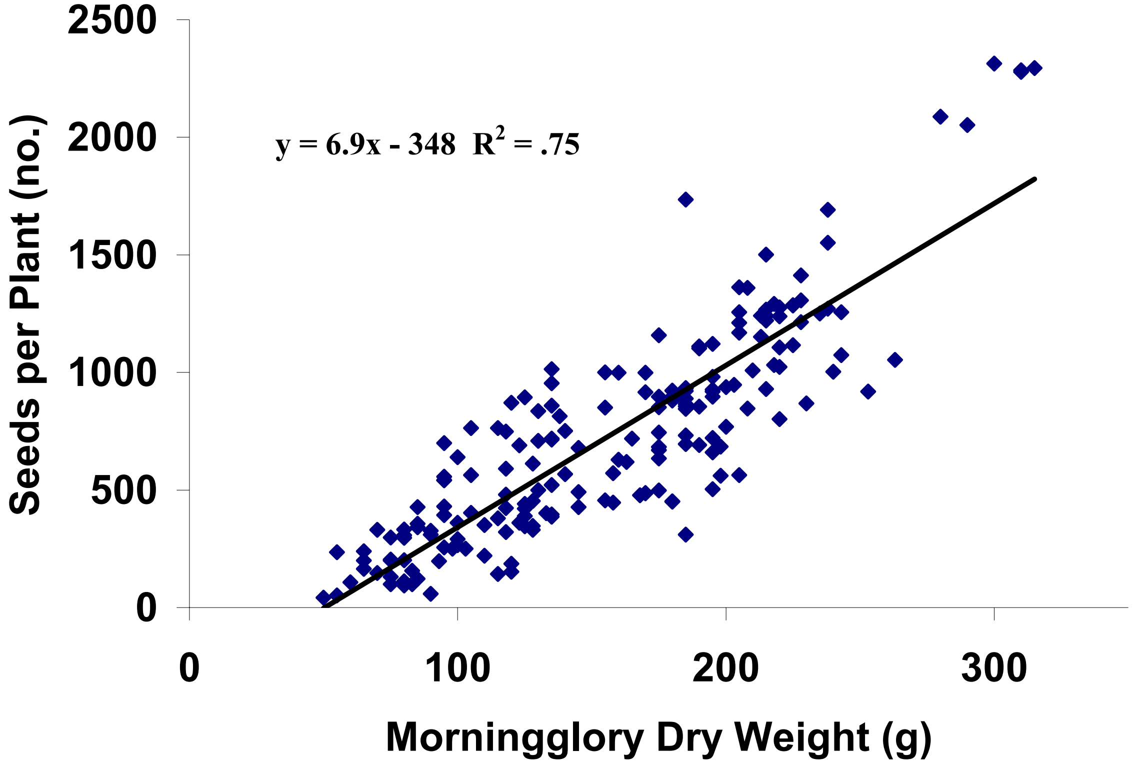


Figure 10. Seed per plant as influenced by morningglory dry weight in field study.

CHAPTER 7

Physiological Behavior of Root Absorbed Flumioxazin in Peanut, Ivyleaf Morningglory, and Sicklepod.

Abstract: Previous research has shown that flumioxazin has the potential to cause peanut injury. In response to this concern, laboratory experiments were conducted to investigate the influence of temperature on flumioxazin-treated peanut seed germination. Also, greenhouse experiments were investigated the influence of six different irrigation intervals after soil-applied flumioxazin preemergence (PRE) application on peanut emergence and injury. Laboratory experiments utilizing ^{14}C-flumioxazin were also conducted to investigate differential tolerances exhibited by peanut, ivyleaf morningglory, and sicklepod to flumioxazin. Flumioxazin treatments containing either water dispersible granular (WDG) or wettable powder (WP) formulation at 1.4 µmol/L did not influence germination compared to non-treated peanut across all temperature regimes. Peanut treated with a WDG or a WP formulation of flumioxazin PRE and receiving irrigation at emergence and at 2 and 4 d after emergence were injured between 40 and 60%, while peanut treated at 8 and 12 d after emergence were injured between 25 and 15%, respectively. Total ^{14}C absorbed by ivyleaf morigglory was 57% of applied while sicklepod absorbed 46%, at 72 hours after treatment (HAT). Peanut absorbed > 74% of applied ^{14}C 72 HAT. A majority of absorbed ^{14}C remained in roots for sicklepod, ivyleaf morningglory, and peanut at all harvest times. Ivyleaf morningglory contained 41% of the parent herbicide 72 HAT while sicklepod and peanut contained only 24 and 11% parent compound, respectively. Regression slopes indicated slower metabolism by ivyleaf morningglory compared to sicklepod and peanut.

Nomenclature: Flumioxazin; ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.] IPOHE; sicklepod, [*Senna obtusifolia* (L.) Irwin and Barneby] CASOB; peanut, *Arachis hypogaea* L., 'NC 10C'.

Key words: Absorption, translocation, metabolism.

Introduction

Flumioxazin was registered for preemergence (PRE) use in peanut (*Arachis hypogaea* L.) in 2001 (Anonymous 2002a, 2002b; Burke et al. 2002). Considerable peanut injury resulted in 2001 from flumioxazin treatments in grower's fields in the mid-Atlantic and Southeast (D. L. Jordan, C. W. Swann, E. Prostko, personal communication). Due to these injury concerns, the flumioxazin product formulation was changed in 2002 from being a water dispersible granular (WDG) to a wettable powder (WP), while percent active ingredient remained unchanged (Anonymous 2002a, 2002b). Current recommendations for PRE herbicide use in North Carolina peanut suggest restricting hectarage treated with flumioxazin until complete understanding of injury becomes apparent (Jordan 2002).

Previous research has shown that flumioxazin has the potential to injure peanut (Askew et al. 1999; Burke et al. 2002; Wilcut et al. 2001). Burke et al. (2002) reported 50 to 67% peanut injury and reduced yield at one North Carolina location from flumioxazin containing treatments. However, injury was less than 2% at two other locations within the same study and yields were not affected. The researchers in these studies hypothesized that injury was likely increased by cool, wet conditions at time of peanut emergence. Wilcut et al. (2001) reported little difference in peanut variety response to flumioxazin PRE. However, injury was significant (≥ 15%) in 1997. Scott et al. (2001) reported 10% peanut injury at one North Carolina location from flumioxazin containing treatments but injury was not visibly apparent at a later rating. Trifluralin plus flumioxazin treatments stunted Texas peanut up to 16% (Grichar and Colburn 1996). No peanut injury was noted 6 to 8 wks after treatment. In a preliminary greenhouse study, Vencill (2002) reported that peanut injury was related to peanut planting depth and flumioxazin placement depth. Swann (2002) reported between 43 and 68% injury in two studies conducted in Virginia in 2000 and 2001, respectively. Injury declined to less than 9% in both of these studies and yield was unaffected compared to other registered peanut treatments. Also, injury was reduced in these studies in plots where rainfall followed flumioxazin application and preceded crop emergence.

Flumioxazin acts by inhibiting protoporphyrinogen oxidase (protoporphyrin IX:oxygen oxidoreductase, EC 1.3.3.4) (Anonymous 1988; Cranmer et al. 2000). Inhibition of this enzyme induces accumulation of protoporphyrin IX due to uncontrolled autooxidation of the substrate (Duke et al. 1991). As protoporphyrin IX accumulates and is exposed to light, toxic oxygen radicals are generated which lead to degradation of plasmalemma and tonoplast membrane lipids and irreversible damage of their membrane function and structure in susceptible plants.

Acifluorfen and sulfentrazone are herbicides with similar modes of action as flumioxazin. Previous research showed that soybean [*Glycine max* (L.) Merr.] exhibited tolerance to acifluorfen due to limited absorption compared to susceptible weed species (Ritter and Coble 1981). However, tolerance of sicklepod to sulfentrazone was due to increased metabolism compared to susceptible coffee senna (*Cassia occidentalis* L.) (Dayan 1996). In another study, Dayan et al. (1997) reported no differences in absorption and translocation of sulfentrazone between relatively tolerant and less tolerant soybean cultivars. Tolerance was found to be due to differential metabolism and differential tolerance to herbicide–induced peroxidative stress. Differential tolerance is expressed by *Ipomoea spp*. and sicklepod, two weed species commonly found in Southeastern peanut (Webster 2001). Tolerance mechanisms of peanut, and mechanisms for *Ipomoea spp.* susceptibility were unknown. Also, elucidation of peanut physiological behavior to root-absorbed flumioxazin may offer insight into injury observed in the field.

In response to peanut injury seen with flumioxazin, experiments were conducted to investigate the influence of temperature on flumioxazin-treated peanut seed germination, as well as the influence of increasing irrigation intervals after soil-applied flumioxazin PRE application on peanut emergence and injury. Experiments were also conducted to investigate the basis for differential tolerance of peanut, ivyleaf morningglory, and sicklepod to root-absorbed flumioxazin.

Materials and Methods

Temperature Experiment

In this experiment, the effect of constant temperatures was evaluated on peanut seed germination. Five peanut seeds (NC 10C) were evenly spaced 5 cm deep in 500 cm^3 lidded glass containers[1] filled with oven-dried sterile sand. The containers were arranged on a thermogradient table (Larsen 1965) in six lanes corresponding to constant temperatures of 15, 20, 25, 30, 35, and 40 C, with five replicate containers per temperature lane. Experiments performed on the gradient table precluded randomization as the zones of temperature were fixed in position (Larsen 1965). Non-treated peanuts received 100 ml of distilled water. Flumioxazin-treated peanuts received a 100 ml solution containing 1.4 μmol/L flumioxazin in either wettable powder (WP) or water dispersable granular (WDG) formulation. This concentration is approximately 2000 times the concentration found in field solution (approximately 0.0007 μmol L^{-1}) after application based on a registered rate (71 g ha^{-1}) and the volume of water in the top 7.62 cm of soil at field capacity, assuming 20% moisture by weight, and no herbicide absorption by the soil (Weber et al. 2000). Germination was recorded each day until experiment was terminated 15 d after experiment initiation. The study was conducted twice.

Data variance was visually inspected by plotting residuals to confirm homogeneity of variance prior to statistical analysis. Both non-transformed and arcsin-transformed data were examined, and transformation did not improve homogeneity. Analysis of variance (ANOVA) was therefore performed on non-transformed percent germination. Trial repetition and linear, quadratic, and higher order polynomial effects of percent germination over time were tested by partitioning sums of squares (Draper and Smith 1981). Regression analysis was performed when indicated by ANOVA. Nonlinear models were used if ANOVA indicated that higher order polynomial effects of percent germination were more significant than linear or quadratic estimates. Estimation used the Gauss-Newton algorithm, a nonlinear least squares technique.

Germination resulting from constant temperature treatments was described by a parabolic model of the form:

$$y = \beta_0 + \beta_1 \text{temp} + \beta_2 \text{temp}^2 \qquad [1]$$

where β_0, β_1, and β_2 are the intercept, first and second order regression coefficients, respectively, and y is the cumulative germination at temperature *temp*. A parabolic model was used to describe the germination of peanut as the constant temperature used in the experiment allowed direct correlation of germination response.

Irrigation Interval Experiment

In this experiment, the effect of increasing time interval between flumioxazin PRE application and irrigation on peanut emergence and injury was evaluated. Ten peanut seeds (NC 10C) were sown at the recommended field spacing and 5 cm depth into 5 L flats containing sandy loam soil, typical of soil in which peanut are grown in the mid-Atlantic and Southeastern Coastal Plain, and placed in a greenhouse maintained at approximately 30 ± 5 C (Jordan 2002). Treatment combinations reflected a two by five factorial treatment arrangement of flumioxazin formulation and simulated rain timing. Immediately after planting, soil was treated with either WDG or WP formulations of flumioxazin PRE at 71 g ai ha^{-1}. A single 1.3 cm simulated intense irrigation treatment applied at 0.04 cm per m using wide angle full cone nozzles[2] in a custom built rainfall apparatus was then applied at 1) immediately after flumioxazin application, 2) peanut emergence [10 d after planting (DAP)], 3) peanut emergence plus 2 d, 4) peanut emergence plus 4 d, 5) peanut emergence plus 8 d, and 6) peanut emergence plus 12 d. A non-flumioxazin treated comparison was included. Peanut emergence from soil surface was evaluated. Peanut injury was visually rated at emergence and 5 d after for peanut receiving irrigation immediately after flumioxazin application, and at emergence and 5 and 10 d after each POST irrigation treatment on a 0 to 100 scale (Frans et al. 1986). Plants were harvested 32 DAP, dried, and weighed. Experimental treatments were completely randomized and each study was repeated in time.

All data were subjected to ANOVA to evaluate the effect of a two (flumioxazin formulation) by five (irrigation treatment timing) factorial treatment arrangement. Treatments were considered fixed effects while trial effects were considered random variables. Non-transformed data for visual evaluations are presented because arcsine square root transformation did not affect data interpretation. ANOVA was conducted with and without the PP non-treated control prior to ensure the control did not bias the conclusions since visually estimated injury ratings were zero. Conclusions are based on the inclusion of the non-treated control in the analysis. Means for appropriate main effects and interactions were separated using Fisher's protected LSD test at P = 0.05. Where interactions occurred, data are presented separately and where interactions did not occur, data are combined.

Plant Material and Growth Conditions for Physiology Experiments

Peanut (NC 10C), ivyleaf morningglory, and sicklepod were grown in 0.5 L pots containing sand in a greenhouse maintained at approximately 30 ± 5 C. There was 16 h photoperiod of natural and supplemental metal halide lighting with an average midday photosynthetic flux density of 700 µmol $m^{-2}s^{-1}$. When plants emerged, they were moved into a growth chamber with 26 C constant temperature and approximately 50% relative humidity. Lighting was provided by fluorescent and incandescent lamps at 500 µmol $m^{-2}s^{-1}$. Studies were arranged as randomized complete block designs with three replications of treatment to evaluate absorption, translocation, and metabolism of flumioxazin. Each study was repeated in time.

Absorption and Translocation

Peanut plants (3.8 or 7.6 cm tall) roots were treated with [phenyl-^{14}C] flumioxazin[3]. A micro-syringe was used to deliver ten 1-µL droplets of ^{14}C-flumioxazin plus 0.25% (v/v) nonionic surfactant[4] (NIS) in HPLC-grade water containing 1850 Bq ^{14}C-flumioxazin [specific activity ^{14}C-flumioxazin was 106 mCi per mmol, 94.2% radiopurity] into 10 ml of 50% Hoagland's solution contained in 30 ml glass vials. Ivyleaf morningglory and sicklepod at the cotyledon stage were treated with 1850 Bq of ^{14}C-flumioxazin placed similarly into 3 ml of 50% Hoagland's solution contained in 5 ml glass vials. Treated plants were harvested

4, 24, 48, or 72 HAT. At harvest, the treated roots from each plant were washed slowly with 10 mL of methanol:water (1/1, v/v) and 0.25% (v/v) NIS solution to remove non-absorbed herbicide from the root surface. A 1 mL aliquot from each solution was added to 25 mL of scintillation cocktail[5] and quantified by liquid scintillation spectroscopy[6] (LSS). Ivyleaf morningglory and sicklepod were then sectioned into roots, stem, and leaves. Peanut were sectioned into leaves and stem, hypocotyl and cotyledon, and roots. These parts were placed into paper bags and dried at 65 C for at least 72 h. The plant parts were then ground with a coffee grinder[7] and a 100 to 200 mg subsample was oxidized in a biological oxidizer[8], where ^{14}C was trapped in scintillation cocktail, and radioactivity quantified by LSS.

Data were subjected to ANOVA with sums of squares partitioned to reflect a split-plot treatment structure and trial effects. The four harvest timings were considered main plots, the three species were considered subplots, and the plant portions and washes were considered sub-subplots. Residuals were plotted, and logarithmic transformations conducted on data where variance increased with increasing means. Following ANOVA, treatment or log transformed treatment means were compared using Fisher's Protected LSD test at the 5% probability level. Where main effects were significant, regressions were used to explain the relationship of measured response over time.

Metabolism

Plants were treated and harvested as previously described. However, only one peanut size (7.6 cm) was used in this study. At harvest, partitioned plant parts were immediately placed in a freezer at –30 C until further analysis. Plant portions were ground in a tissue homoginizer[9] with 10 ml of acetonitrile. The homogenate was then rinsed into a vacuum filtration apparatus with an additional 10 to 15 ml of solvent. The remaining extracted plant material was oxidized and non-extracted ^{14}C quantified as previously described. The filtrate was evaporated to near dryness and then brought to 0.5 ml volume with acetonitrile, shaken, and stored at 4 C until further analysis. One hundred and fifty µl of each sample was spotted on a 20 by 20 cm silica gel thin layer chromatography (TLC) plate[10] and developed to a 16-cm solvent front to separate the parent herbicide from possible metabolites. The solvent consisted of benzene:acetone (2:1, v/v). Plates were partitioned into nine 2-cm wide lanes. A standard of 10 µl stock radiolabeled herbicide solution was spotted on the first lane of each plate. The remaining eight lanes received a single replicate of a treated plant portion sample from each of the three species for the two runs of the studies. Potential metabolites were identified and quantified using a radiochromatogram scanner[11] that determined radioactive positions and corresponding R_f values. Peak area was calculated using Win-Scan software[12] with smoothing set to 13-point cubic and background excluded from peak area calculation. Comparing R_f values from a ^{14}C-flumioxazin standard and the retention times within samples identified the non-metabolized ^{14}C flumioxazin parent. Methodology was a modification of those supplied by Valent USA. Statistical procedures were similar to those previously described for absorption and translocation data.

Results and Discussion

Temperature Experiment

Flumioxazin treatments containing either formulation did not influence germination compared to non-treated peanut across all temperature regimes ($P > 0.05$); therefore, data were combined for presentation (Figure 1). When treated with constant temperature, peanut germinated over a range of 15 to 40 C, with the optimum germination occurring at 30 C (100%). In the field, extension recommendations call for peanut to be planted into soil that are ≥ 18 C for germination to proceed at an acceptable rate (Jordan 2002). These results show that stand reduction after flumioxazin PRE application under cool, wet conditions is likely not due to lack of peanut germination. Thus, injury is likely to occur after peanut emergence from either activation of absorbed flumioxazin by sunlight or splashing of flumioxazin-treated soil onto emerging peanut seedlings. Cotton injury from splashing of treated soil onto foliage has been observed (Wilcut et al. 2000). Because these experiments were conducted in pure sand and herbicide binding would likely increase with increasing clay or organic matter content, soil type would likely not influence observed results. Field research has shown that peanut response to flumioxazin was not influenced by cultivar (Main et al. 2001; Murphree et al. 2002).

Greenhouse Irrigation Interval Experiment

Flumioxazin formulation or experimental run did not influence peanut emergence or injury at either rating; therefore, data were combined for presentation. The main effect of timing of irrigation treatment was significant for peanut injury and peanut dry weight ($P < 0.05$), but not emergence ($P > 0.05$). At the first-evaluation (5 DAT), peanut receiving irrigation immediately after PRE application were injured 3% (Table 1). Peanut receiving irrigation at emergence, 2, or 4 d after emergence were injured between 40 and 60%. Peanut receiving irrigation at 8 or 12 d after emergence were injured less (25 and 15%, respectively). At the second-evaluation (10 DAT), peanut in flats receiving irrigation immediately after PRE application had no visible injury. However, peanut receiving irrigation at emergence, 2, and 4 d after emergence were still injured 30 to 50%. Peanut receiving irrigation at 8 or 12 d after emergence were injured 15% and 5%, respectively.

Peanut dry weight reflected injury levels (Table 1). Peanut receiving rainfall immediately after PRE application or 12 d after emergence weighed 5.1 or 4.5g, respectively, similar to untreated (4.8 g) at 32 DAP. Peanut in flats receiving irrigation at emergence, 2, 4, or 8 d after emergence weighed less, between 0.75 and 1.9 g with no differences among these treatments.

These results agree with observations by Swann (2002) that splashing of flumioxazin-treated soil or surface water containing flumioxazin onto emerged peanut seedlings causes injury if rainfall did not occur between flumioxazin application and peanut emergence.

Absorption and Translocation

Growth stage by experimental run and harvest timing by run interactions were not significant ($P > 0.05$); therefore, data were combined over experimental runs for presentation. The main effects of harvest time, species, and plant portion influenced the absorption and translocation of ^{14}C by peanut, ivyleaf morningglory, and sicklepod ($P < 0.05$). As a result, the influence of harvest time, species, and plant portion within species are presented separately.

At 4 HAT, absorption of applied ^{14}C was 42% and 35% by ivyleaf morningglory and sicklepod, respectively (Figure 2). Total ^{14}C absorbed by ivyleaf morningglory 72 HAT was 57% while sicklepod absorbed 46%. Most herbicide was absorbed within the first 4 HAT for both weed species. A majority of absorbed ^{14}C remained in the roots for both sicklepod and ivyleaf morningglory across time (Figures 3 and 4). Sicklepod translocated 5% of absorbed ^{14}C to stem and 18% to leaves 72 HAT (Figure 3). Ivyleaf morningglory translocated absorbed ^{14}C similarly to stem (9%) and less (7%) to leaves 72 HAT (Figure 4).

Smaller peanut (3.8 cm tall) absorbed 24% of applied ^{14}C 4 HAT and absorption increased to 72% 72 HAT (Figure 2). Larger peanut (7.6 cm tall) absorbed more than twice the applied ^{14}C at 4 HAT (74%) compared to small peanut, and absorbed 99% of the applied ^{14}C at 72 HAT. Most ^{14}C was absorbed within the first 4 HAT for larger peanut. Smaller peanut exhibited linear ^{14}C absorption through all harvest timings. Larger peanut likely absorbed ^{14}C more rapidly due to increased transpiration compared to smaller peanut. The majority of absorbed ^{14}C remained in the roots for both peanut sizes across time (Figure 5). Larger peanut (7.6 cm) translocated 10% of absorbed ^{14}C to leaves and stem and 6% to hypocotyl and cotyledon 72 HAT. Smaller peanut (3.8 cm) translocated absorbed ^{14}C similarly to leaves and stem 72 HAT.

Absorption of ^{14}C for the three species including two peanut sizes was larger peanut (7.6 cm) > smaller peanut (3.8 cm) > ivyleaf morningglory > sicklepod. Since more absorption occurred in peanut, a tolerant plant, compared to ivyleaf morningglory, a susceptible plant, these data suggest that differential response exhibited by these species to root-absorbed flumioxazin is not related to absorption. Also, because limited acropetal translocation to tissue in which flumioxazin caused peroxidation could be expressed occurred in all species, this suggests that differential response by plants to root-absorbed flumioxazin is not related to translocation in these species.

Metabolism

Experiment by main effect interactions were not significant ($P > 0.05$), thus data were combined for presentation. The main effects of harvest time and species significantly influenced metabolism of absorbed ^{14}C-flumioxazin ($P < 0.05$); therefore, species and harvest time are presented separately. However, differences between accumulation of metabolites in plant parts were not discernable ($P > 0.05$). Recovery of applied radioactivity was > 95%. Of the recovered radioactivity, 10% remained bound in the plant debris after extraction. Thus, the amount of herbicide metabolism in the stem or leaves was the sum of extracted metabolites and is reported as percent of extracted.

Most metabolism occurred within the first 4 h in sicklepod, ivyleaf morningglory, and peanut (Figures 6 and 7). Sicklepod and peanut metabolized flumioxazin rapidly with only 40 and 33% of absorbed flumioxazin remaining as parent herbicide, respectively, at 4 HAT (Figures 6 and 7). In contrast, ivyleaf morningglory contained 49% of the parent herbicide 4 HAT and 41% at 72 HAT (Figure 6). By 72 HAT, sicklepod and peanut contained only 24 and 11% parent compound, respectively. Regression slopes also indicated slower metabolism by ivyleaf morningglory compared to sicklepod and peanut. Visual symptoms of peroxidation of tissue began to appear in the leaves of ivyleaf morningglory 48 HAT and plants were near death 72 HAT. No visible injury was apparent in peanut or sicklepod. Extrapolated half-life of flumioxazin is 0.8, 1.3, and 2.5 d for peanut, sicklepod, and morningglory. These data suggest that differential metabolism is the main factor influencing flumioxazin tolerance in ivyleaf morningglory, sicklepod and peanut. Our results are in agreement with Dyan et al. (1996, 1997).

Because peanut were shown to metabolize root-absorbed flumioxazin more than three times as quickly as susceptible ivyleaf morningglory, these studies suggest that flumioxazin root-absorbed will likely be metabolized by peanut before visible injury occurs. These studies further suggest that flumioxazin injury observed on seedling peanut is likely caused by rainfall occurring after flumioxazin application and peanut emergence, if rainfall did not occur prior to peanut emergence. Because the mid-Atlantic and Southeastern peanut production areas frequently receive intermittent spring rains at time of peanut planting, producers should plant peanut and apply flumioxazin PRE before a predicted rain event. Under ideal conditions, peanut can begin to emerge in the field in 7 d for smaller seeded varieties, and 10 d for larger seeded varieties (Jordan 2002). Thus, peanut growers need to anticipate receiving rain on soil treated with flumioxazin PRE within 6 d of application to lesson probability peanut injury.

Sources of Materials

[1] Pyrex® 500 ml lidded glass container. No. 3250, Corning Inc., Corning, NY 14831.

[2] TeeJet® hollow cone spray tips. TeeJet East, 124 A West Harrisburg St. Dillsburg, PA 17019.

[3] Valent® USA Corporation, P.O. Box 8025, Walnut Creek, CA 94596-8025

[4] Induce® nonionic low foam wetter/spreader adjuvant contains 90% nonionic surfactant (alkylarylpolyoxyalkane ether and isopropanol), free fatty acids, and 10% water. Helena Chemical Co., Suite 500, 6075 Poplar Avenue, Memphis, TN 38137.

[5] ScintiVerse® SX18-4 Universal Liquid Scintillation Cocktail, Fisher Scientific, Fairlawn, NJ 07410.

[6] Packard® TRI-CARB 2100TR Liquid Scintillation Spectrometer, Packard Instrument Company, 2200 Warrensville Rd. Downers Grove, IL 60515.

[7] Coffee Mill®. Mr. Coffee, 24700 Miles Rd, Bedford Heights, OH 44146-1399.

[8] Harvey® biological oxidizer. J. Harvey Instrument Corporation, 123 Patterson Street, Hillsdale, NJ 07642.

[9] Pyrex® Tissue Homoginizer No. 7727-40, Corning Inc., Corning, NY 14831.

[10] Whatman® K6F Silica Gel 60A Thin Layer Chromatography Plates, Whatman Inc, Clifton, NJ 07013.

[11] Bioscan System 200 Imaging Scanner, Bioscan, 4590 MacArthur Blvd. NW, Washington, DC 20007.

[11] Lablogic Win-Scan Radio TLC Version 2.2 (5) 32-bit, Distributed by BioScan, 4590 MacArthur Blvd. NW, Washington, DC 20007.

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Table 1. Injury observed on greenhouse grown peanut 5 and 10 DAT and peanut dry weight 32 DAP from flumioxazin PRE treatment and receiving irrigation (1.27 cm) at various treatment timing.[ab]

	Injury		Dry weight per plant
Irrigation treatment timing	5 DAT	10 DAT	
	%		g
Immediately after flumioxazin PRE treatment	3	0	5.1
Peanut emergence	60	55	0.8
Peanut emergence plus 2 d	50	40	0.9
Peanut emergence plus 4 d	40	30	1.4
Peanut emergence plus 8 d	25	15	1.9
Peanut emergence plus 12 d	15	5	4.5
Non-treated	0	0	4.8
LSD	13	11	2.2

[a] Data averaged over trials. LSD conducted at $P = 0.05$.

[b] Abbreviations: DAT, days after treatment; DAP, days after planting; PRE, preemergence.

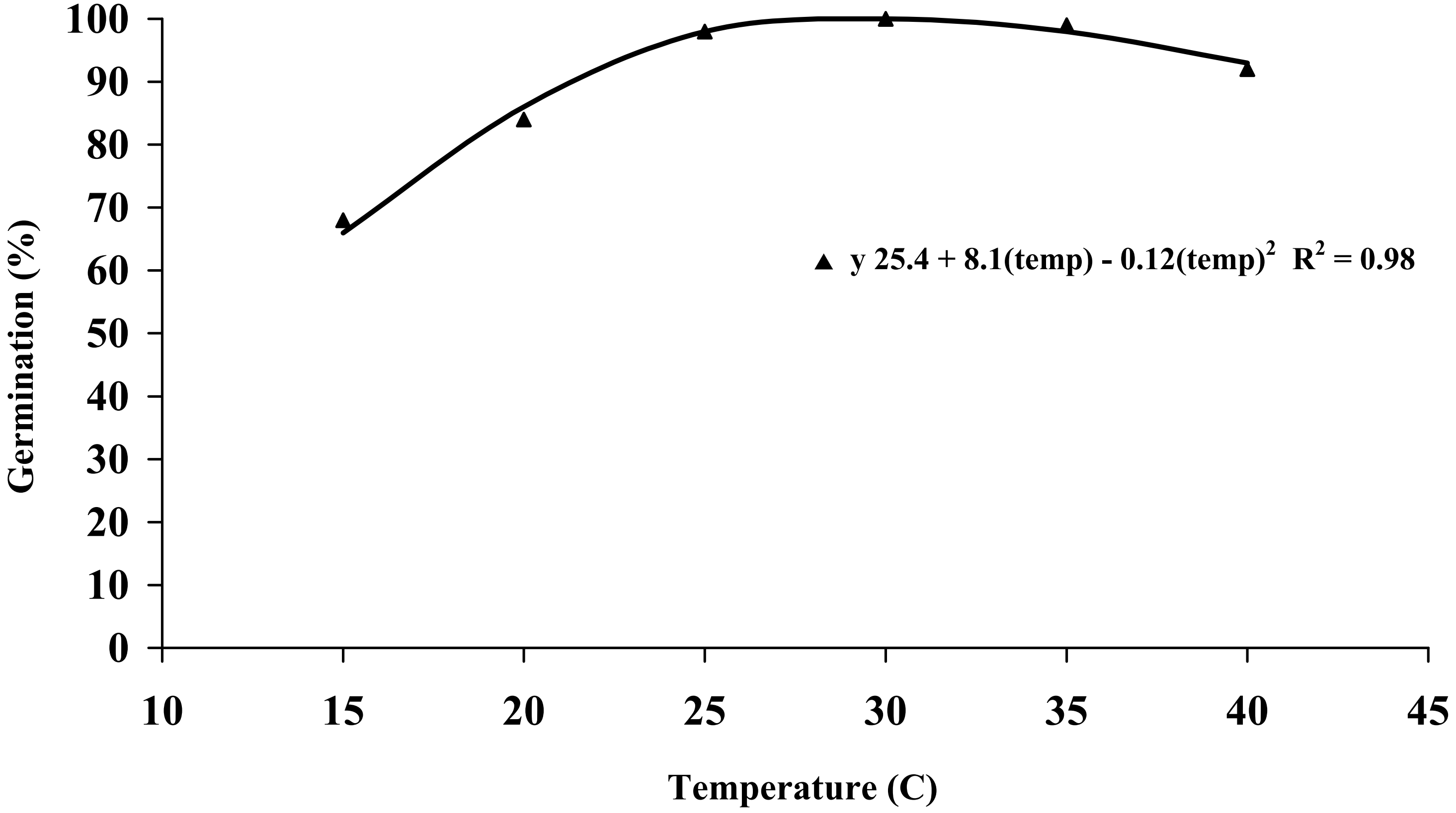

Figure 1. Influence of constant temperature on cumulative germination of treated and untreated peanut seed at 10 d.

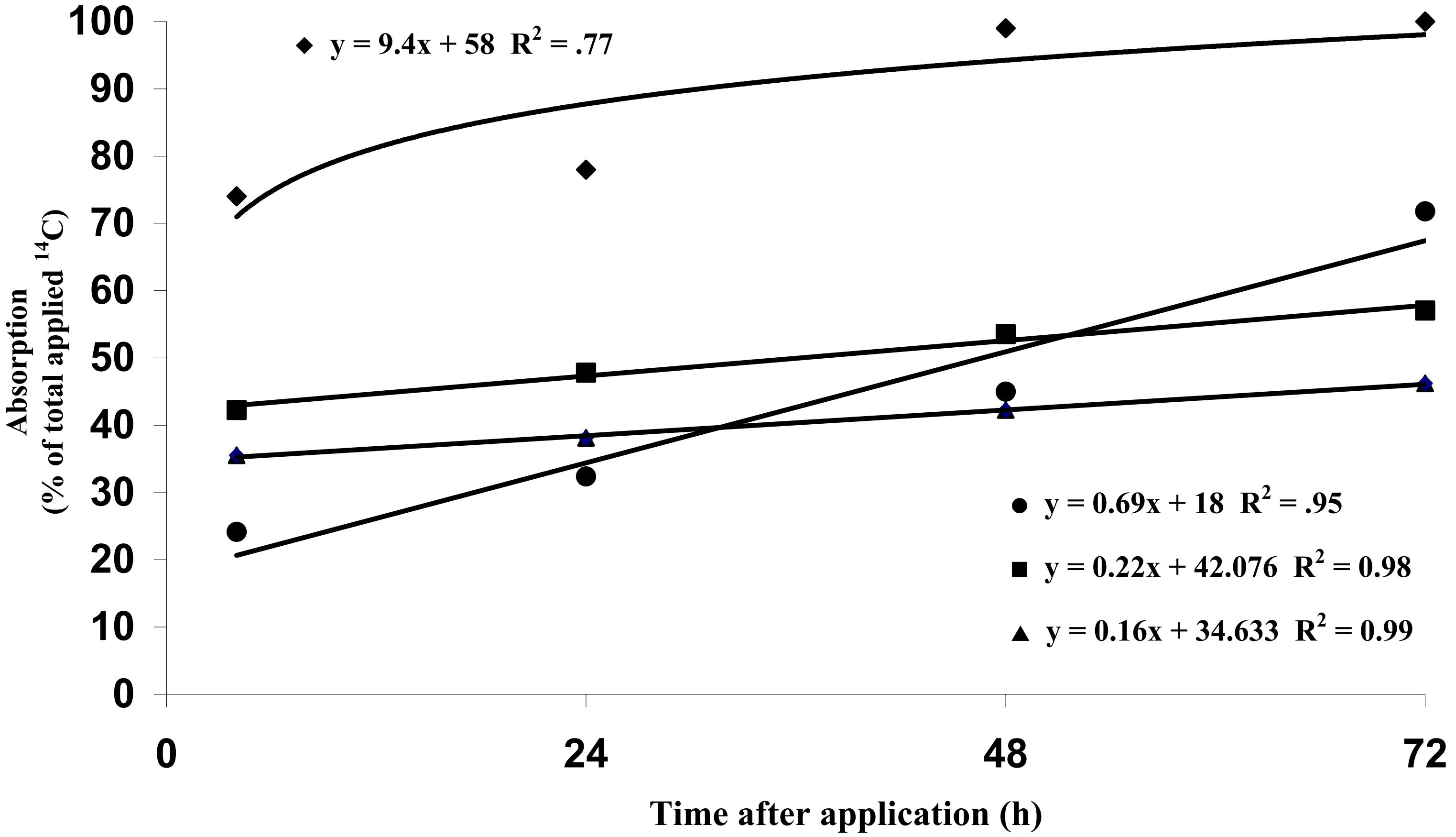

Figure 2. Absorption of ^{14}C-flumioxazin by larger peanut(◆), smaller peanut (●), ivyleaf morningglory (■), and sicklepod (▲), over time reported as percent of applied.

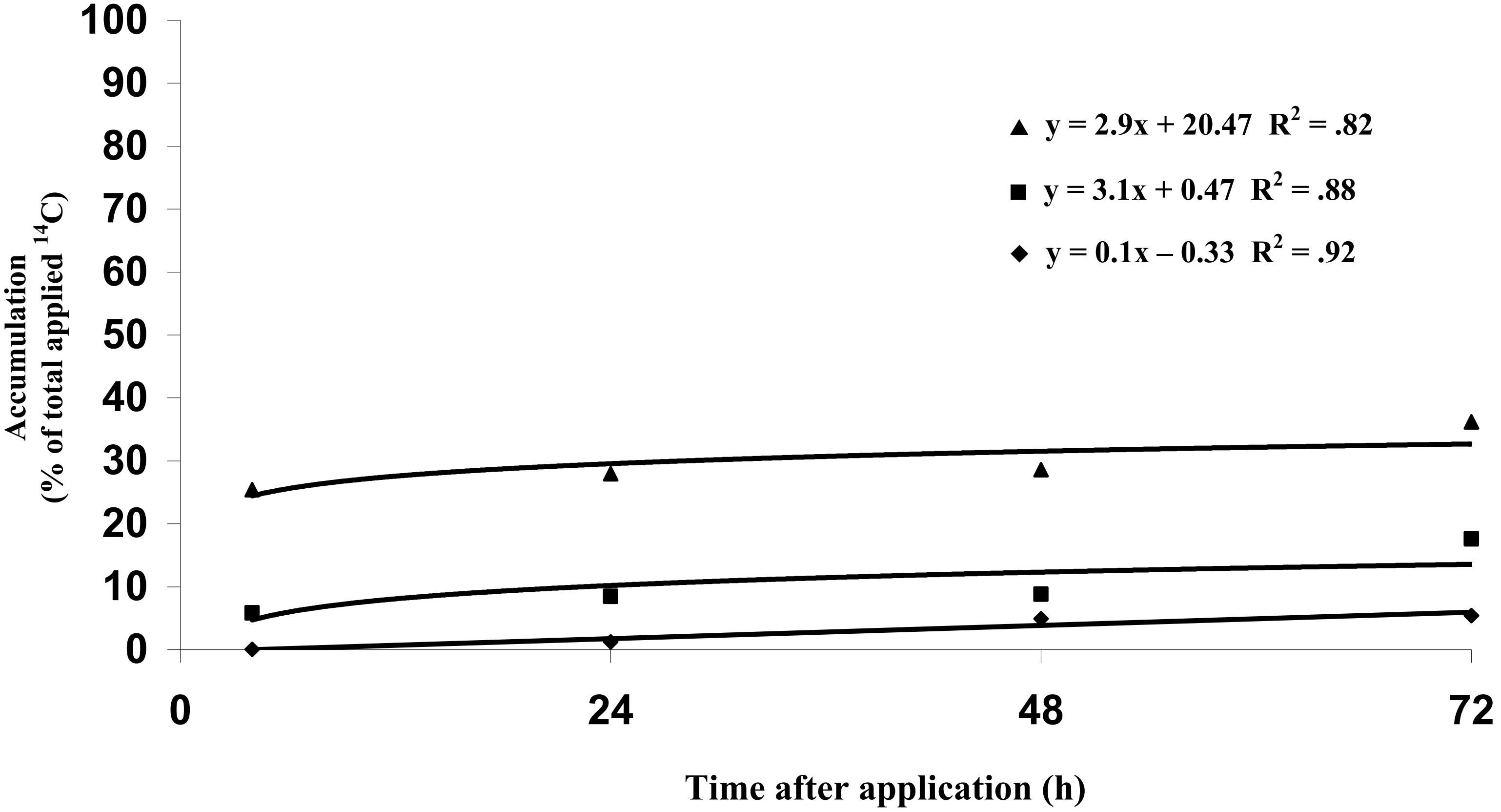

Figure 3. Accumulation of ^{14}C-flumioxazin in leaves (◆), stem (■), and roots (▲), of sicklepod reported as percent of applied.

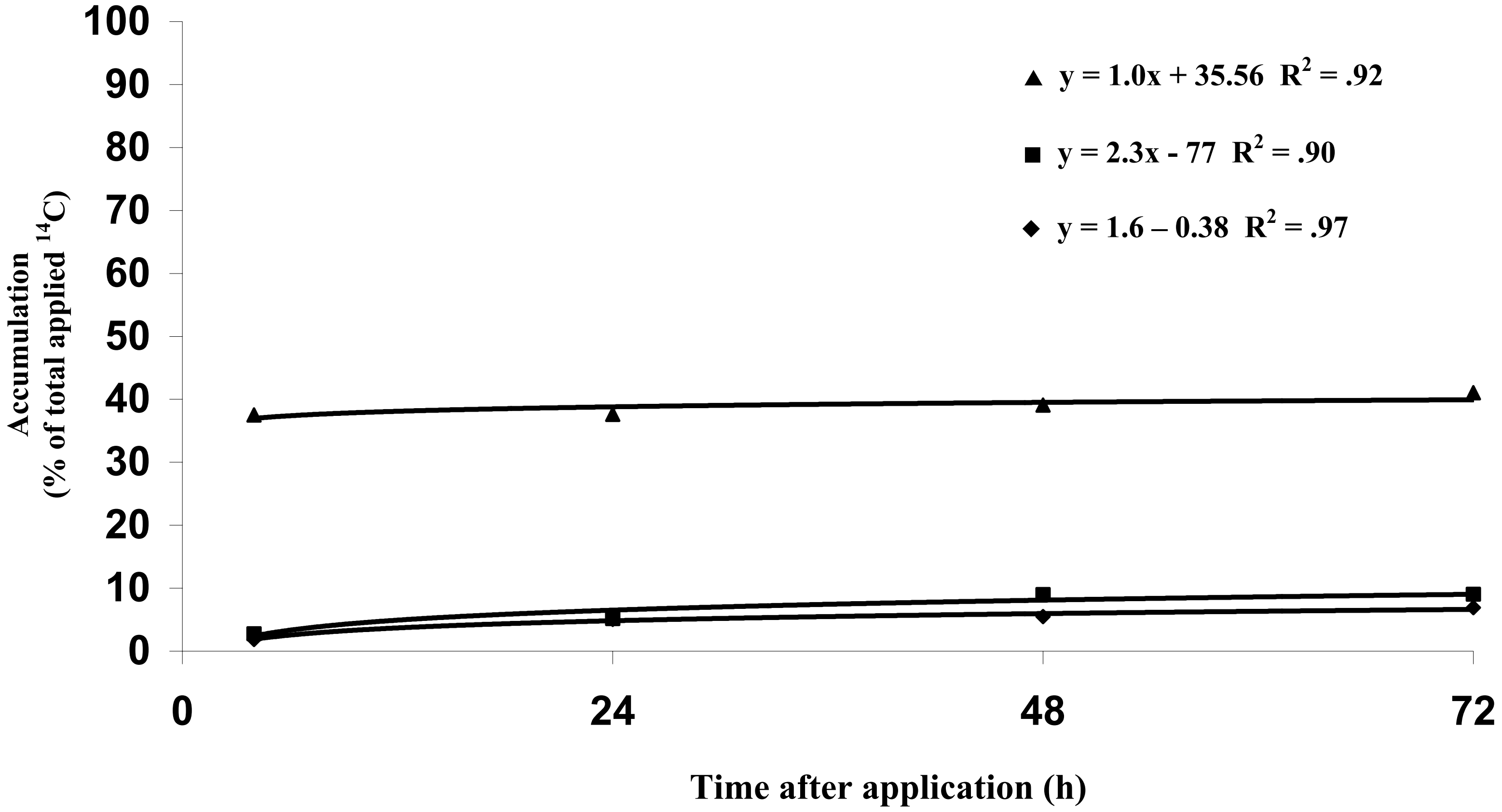

Figure 4 Accumulation of ^{14}C-flumioxazin in leaves (◆), stem (■), and roots (▲), of morningglory reported as percent of applied.

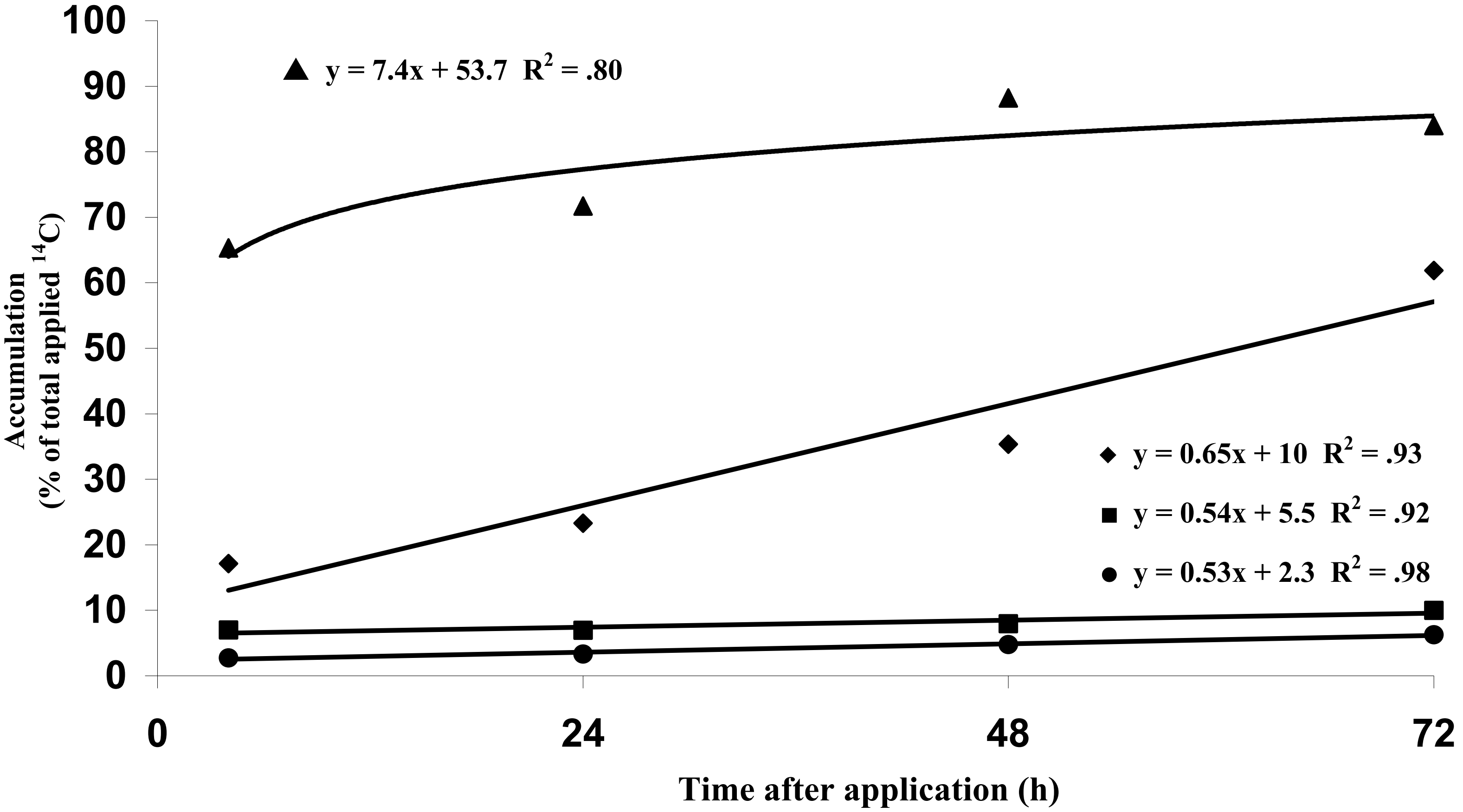

Figure 5. Accumulation of ^{14}C-flumioxazin in leaves and stem (●), hypocotyl and cotyledon (■), and roots of 3.8 cm tall (▲) and 7.6 cm tall (◆) peanut reported as percent of applied.

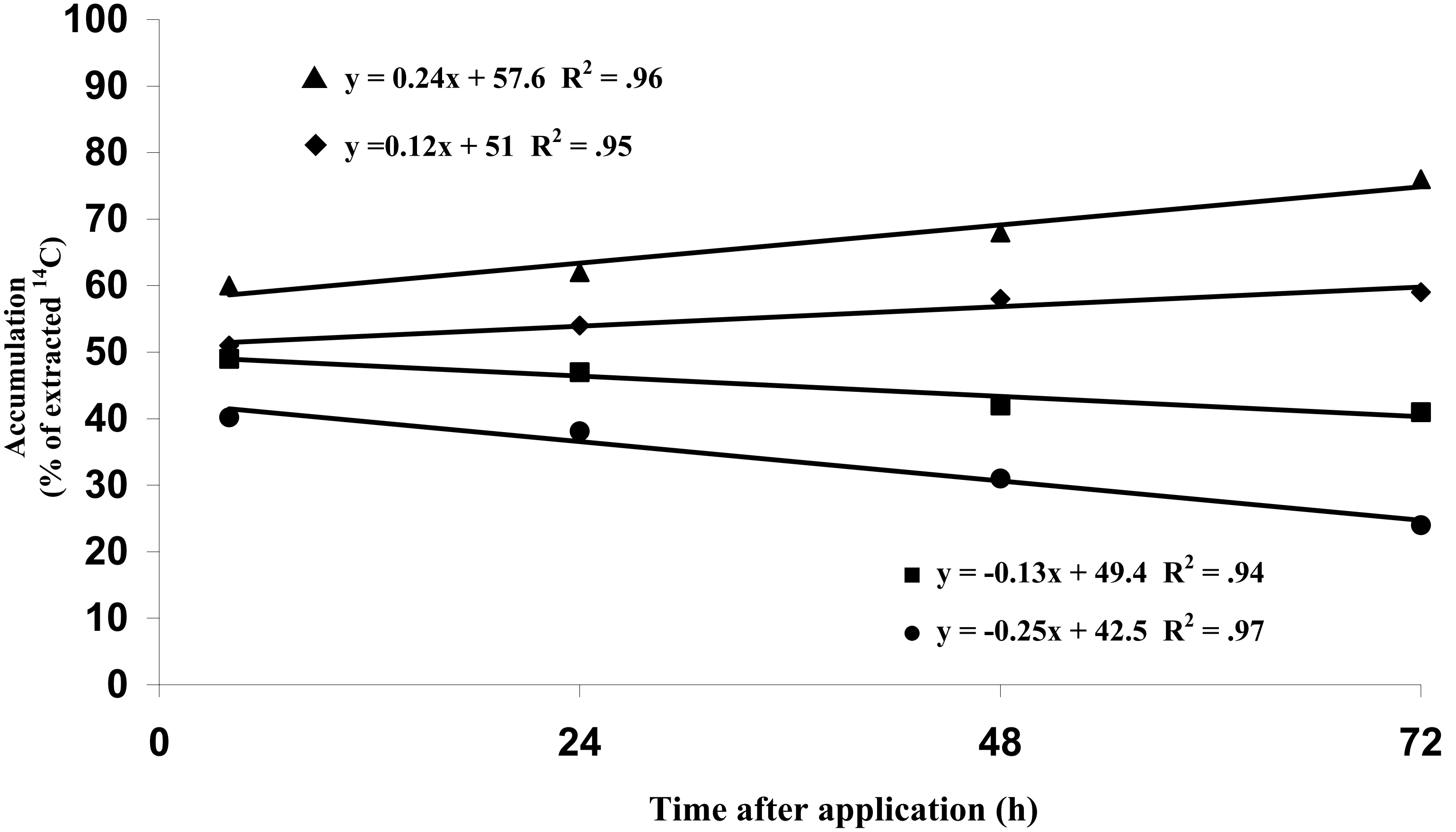

Figure 6. Accumulation of metabolites (▲) and parent flumioxaxin (●) in sicklepod as well as accumulation of metabolites (◆) and parent flumioxaxin (■) in ivyleaf morningglory reported as percent of extracted.

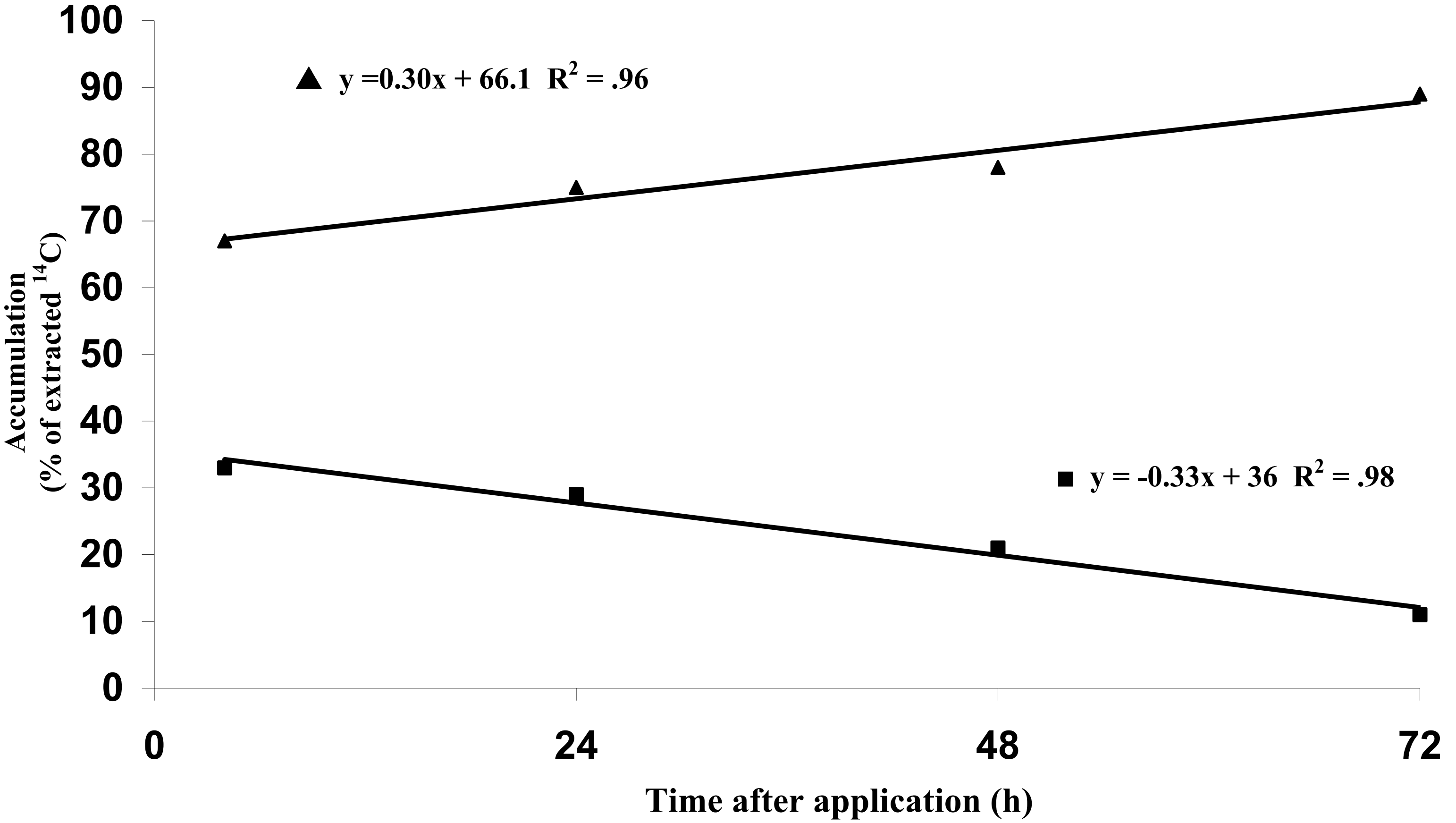

Figure 7. Accumulation of metabolites (▲) and parent flumioxaxin (■) in peanut reported as percent of extracted.