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WEED SCIENCE

Cotton Response to Imazapic and Imazethapyr Applied to a Preceding Peanut Crop

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INTERPRETIVE SUMMARY

Knowledge of the potential for herbicide residues to persist and damage rotational crops is important when developing and recommending weed management strategies. Peanut growers have begun using the imidazolinone herbicides imazapic (Cadre) and imazethapyr (Pursuit). These residual herbicides control a broad spectrum of broadleaf weeds plus nutsedge species. Cotton, which can be injured by residues of imidazolinone herbicides, commonly is rotated with peanut in North Carolina and across the southeastern production region.

Field experiments were conducted in North Carolina to determine the effects of imazapic and imazethapyr applied to peanut on the growth and yield of cotton planted the following year. Both crops were grown using conventional tillage systems. Imazapic was more injurious to cotton when applied preplant incorporated to the preceding peanut crop, compared with postemergence application. Imazapic applied preplant incorporated at the manufacturer's recommended rate and twice the recommended rate visibly injured cotton, and imazapic at twice the recommended rate delayed cotton maturity and reduced yield 44%. Imazapic applied postemergence at the recommended rate and twice the recommended rate caused minor injury to cotton but did not affect yield. Less carryover of imazapic applied postemergence was likely due to photodegradation by sunlight.

Imazethapyr applied postemergence to peanut at the recommended rate did not injure cotton. Imazethapyr applied postemergence at twice the recommended rate caused minor visible injury to cotton but did not affect yield. No treatment affected cotton fiber quality.

Our results suggest the risk of imazethapyr carryover to cotton planted the year following postemergence application to peanut is minimal. The results substantiate the manufacturer's claim that cotton can be planted 9.5 mo after postemergence application of imazethapyr if 41 cm (16 in) of rainfall or irrigation are received between the time of application and the end of October of the application year. The results also indicate little risk of imazapic carryover to cotton if applied postemergence the preceding year. Imazapic carryover to cotton following postemergence application to peanut is observed occasionally in growers' fields, whereas carryover of imazethapyr is seldom seen.

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ABSTRACT

Knowledge of the potential for herbicide residues to persist and damage rotational crops is important when developing and recommending weed management strategies. Peanut (*Arachis hypogaea* L.) commonly is planted in rotation with cotton (*Gossypium hirsutum* L.) in North Carolina. The imidazolinone herbicides imazapic {(±)-2-[4,5-dihydro-4-methyl-4 (1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid} and imazethapyr {(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid} are used commonly in peanut. Field experiments were conducted to determine the effects of imazapic and imazethapyr applied to peanut on the growth and yield of cotton planted the following year. Imazapic was more injurious to cotton when applied preplant incorporated to the preceding peanut crop, compared with postemergence application. Imazapic applied preplant incorporated at 35 g a.i. ha^{-1}, or half the manufacturer's recommended rate, did not injure cotton. Imazapic applied preplant incorporated at 70 and 140 g ha^{-1} visibly injured cotton 19 to 58%, and imazapic at 140 g ha^{-1} delayed cotton maturity and

reduced yield 44%. Imazapic applied postemergence at 70 to 140 g ha^{-1} caused minor injury to cotton but did not affect yield. No cotton injury was noted following imazapic applied postemergence at 35 or 53 g ha^{-1}. Imazethapyr applied postemergence to peanut at the recommended rate of 70 g a.i. ha^{-1} did not injure cotton. Imazethapyr applied postemergence at 140 g ha^{-1} caused visible injury to cotton but did not affect yield. No treatment affected cotton fiber quality.

Optimum peanut (*Arachis hypogaea* L.) production requires excellent weed control. Peanut, due to its canopy architecture, is less competitive with weeds than are corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] (Brecke and Colvin, 1991; Wilcut et al., 1995). Peanut is a low-growing crop that shades row middles slowly and allows emergence of weeds over a longer period than more competitive crops (Wilcut et al., 1994). Moreover, weeds greatly interfere with digging and threshing operations.

Peanut producers use soil-applied and postemergence herbicides extensively in an effort to keep the crop weed-free (Jordan and York, 1999; Wilcut et al., 1994). Soil-applied herbicides such as pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine], ethalfluralin [*N*-ethyl-*N*-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl)benzenamine], and metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] control annual grasses and small-seeded dicot weeds such as pigweed species (*Amaranthus* spp.) and common lambsquarters (*Chenopodium album* L.) (Jordan and York, 1999; Wilcut et al., 1995). Postemergence herbicides such as acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid}, bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide], paraquat (1,1'-dimethyl-4,4'-bipyridinium dichloride), and 2,4-DB [4-(2,4-dichlorophenoxy)butanoic acid] control nutsedge and annual dicot species such as common cocklebur (*Xanthium strumarium* L.), morningglory species (*Ipomoea* spp.), common ragweed (*Ambrosia artemisiifolia* L.), and prickly sida (*Sida spinosa* L.). Lack of residual activity from these postemergence herbicides and multiple flushes of weed germination often require growers to make two or more postemergence herbicide applications (Wilcut et al., 1987, 1991).

Imazethapyr, an imidazolinone herbicide registered in 1991, was the first herbicide for peanut to provide broad spectrum residual control of dicot weeds and nutsedge species (Wilcut et al., 1995; York et al., 1995). Imazapic, an imidazolinone herbicide registered for use in peanut in 1996, also controls a broad spectrum of dicot weeds, and it is more effective than imazethapyr on some troublesome dicot weeds, yellow nutsedge (*Cyperus esculentus* L.), and purple nutsedge (*Cyperus rotundus* L.) (Grichar and Nester, 1997; Richburg et al., 1995, 1996; Webster et al., 1997; Wilcut et al., 1996).

Carryover of herbicides to rotational crops can be a significant problem for producers. Cotton commonly is rotated with peanut in the southeastern production region. Most herbicides registered for use in peanut do not restrict rotation to cotton. However, labels for imazapic (Cadre DG Peanut Herbicide label, BASF Corp., Research Triangle Park, NC) and imazethapyr (Pursuit DG Herbicide label, BASF Corp., Research Triangle Park, NC) include specific restrictions on rotation to cotton. The imazapic label prohibits planting cotton within 18 mo of application to peanut. The imazethapyr label also specifies an 18-mo rotational restriction for cotton in most cases. The exception is a 9.5-mo restriction for imazethapyr applied postemergence to peanut on sandy loam or loamy sand soil and receipt of greater than 41 cm of rainfall or irrigation following application through October of the application year.

Imidazolinone herbicides can persist and damage cotton and other crops planted the year after herbicide application (Curran et al., 1992; Johnson and Talbert, 1993, 1996; Johnson et al., 1995; Jourdan et al., 1998; Marsh and Lloyd, 1996; Moyer and Esau, 1996; Vencill et al., 1990; Walsh et al., 1993). Imidazolinone herbicides are primarily degraded microbially (Flint and Witt, 1997). Thus, cool and dry conditions enhance the potential for carryover. Persistence of imidazolinone herbicides and residue bioavailability also are influenced by method of application and soil pH, organic matter, texture, and moisture (Curran et al., 1992; Gan et al., 1994; Johnson et al., 1995; Loux and Reese, 1993; Mangels, 1991; Marsh and Lloyd, 1996; Renner et al., 1988; Stougaard et al., 1990).

Knowledge of the potential for herbicide residues to persist and damage rotational crops is important when developing and recommending weed management strategies (York, 1993). Research was conducted in North Carolina to determine the potential for imazapic and imazethapyr applied to peanut to adversely affect cotton planted the following year.

MATERIALS AND METHODS

The experiment was conducted in separate fields at the Upper Coastal Plain Research Station near Rocky Mount, NC from 1991 through 1994. The soil was a Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Paleudults). During the rotations, the organic matter content and pH were 1.1% and 5.3 in 1991-1992; 0.8% and 5.5 in 1992-1993; and 1.6% and 6.0 in 1993-1994. Soils were characterized using the chromic acid colorimetric method (Nelson and Sommers, 1982) for organic matter determination.

Peanut was planted in the first year of the experiment. Plot size was eight rows, 91-cm by 24 m. Seedbed preparation for peanut included disking followed by bedding with in-row subsoiling. Pendimethalin at 1.1 kg a.i. ha^{-1} was applied to all peanut plots and incorporated on the bed with a power-driven, vertical-action tiller. Peanut cv. NC 9 was planted 14 May 1991, 13 May 1992, and 13 May 1993.

Treatments to peanut in 1991 included imazapic at 35, 70, and 140 g ha^{-1} applied preplant incorporated or early postemergence, and imazethapyr at 70 g ha^{-1} applied early postemergence. In 1992, it became apparent that imazapic would be positioned in the marketplace as a postemergence herbicide. Treatments in 1992 and 1993 included imazethapyr at 70 and 140 g ha^{-1} applied early postemergence, and imazapic at 35, 53, 70, 105, and 140 g ha^{-1} applied postemergence. A nonionic surfactant (X-77 Spreader, Loveland Industries Inc., Greeley, CO) at 0.25% ($v\ v^{-1}$) was included with early postemergence and postemergence herbicides. A no-imidazolinone herbicide check was included each year. In addition to pendimethalin preplant incorporated, check plots received the nonresidual herbicides paraquat at 140 g a.i. ha^{-1} applied early postemergence followed by the sodium salt of acifluorfen at 280 g a.i. ha^{-1} plus the sodium salt of bentazon at 560 g a.i. ha^{-1} applied postemergence.

Early postemergence treatments were applied 14, 16, and 14 d after planting in 1991, 1992, and 1993, respectively. Postemergence treatments were applied 28, 29, and 26 d after planting in 1991, 1992, and 1993, respectively. Herbicides were applied as broadcast sprays using a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles and calibrated to deliver 230 L ha^{-1} at 207 kPa.

Normal production practices were used in the peanut crop. The four center rows of each plot were harvested in 1992 and 1993; yield was not recorded in 1991. After peanut harvest, the test site was disked once. The site was disked again the following spring and, with known reference points to ensure locating plots in the same area as in the previous year, bedded with in-row subsoiling. All tillage operations were performed parallel to the peanut rows to minimize lateral movement of herbicides to adjacent plots. Plot length for cotton was reduced to 15 m to compensate for any longitudinal movement of herbicides. All data on cotton were recorded from the center two rows of the eight-row plots.

Cotton cv. DES 119 was planted in 91-cm rows on 4 May 1992, 12 May 1993, and 29 April 1994. Pendimethalin at 1.1 kg ha^{-1} was applied prior to planting and incorporated on the beds with a power-driven, vertical-action tiller. Fluometuron {*N*,*N*-dimethyl-*N*'-[3-(trifluoromethyl)phenyl]urea} at 1.1 kg a.i. ha^{-1} was applied preemergence. The few weeds escaping this treatment were removed by hand. Other production practices were standard for cotton grown in eastern North Carolina.

Cotton injury was estimated visually 3, 6, and 16 wk after planting, using a scale of 0 = no injury to 100 = complete crop death. Cotton stand was determined by counting all plants in the center two rows of the plots following cotton defoliation. In 1992 only, 10 adjacent plants from each of two randomly selected sections of row in each plot were mapped about 3 wk prior to harvest to determine boll production and boll distribution on plants (Mauney, 1986). Cotton was harvested with a spindle picker. A subsample of harvested seedcotton from each plot was collected and used for percent lint determination.

Fiber length, fiber length uniformity, fiber strength, and micronaire were determined by high volume instrumentation testing (Perkins et al., 1984).

The experimental design was a randomized complete block with treatments replicated four times. Data were subjected to analysis of variance, and means were separated by Fisher's protected LSD test at P = 0.05. Cotton data from 1993 and 1994 were pooled when a year by treatment interaction was not observed.

RESULTS AND DISCUSSION

Peanut yields were similar with all treatments in 1992 and 1993. Pooled over treatments, yields were 4840 and 3600 kg ha^{-1} in 1992 and 1993, respectively (data not shown).

Imazethapyr applied at the manufacturer's recommended rate of 70 g ha^{-1} early postemergence to peanut in 1991 did not cause visible injury to cotton in 1992 nor affect cotton stand, boll production, or seedcotton yield (Table 1). Imazapic was more injurious to cotton when applied preplant incorporated to the preceding peanut crop compared with early postemergence application. Imazapic at 35 g ha^{-1}, half the manufacturer's recommended rate, applied preplant incorporated or early postemergence did not adversely affect cotton. Imazapic at 70 g ha^{-1} applied early postemergence to peanut also did not injure cotton, but imazapic at the same rate applied preplant incorporated injured cotton 19% 6 wk after planting. Cotton stand, boll production, and yield were unaffected by imazapic at 70 g ha^{-1} regardless of method of application.

Imazapic at 140 g ha^{-1} injured cotton 58 and 20% when applied preplant incorporated and early postemergence, respectively, to the preceding peanut crop (Table 1). Injury symptoms, typical of imidazolinone herbicides, included stunting, shortened internodes, and yellowish-orange color of young leaves. Symptoms of imazapic injury developed slowly. Injury was first apparent about 3 wk after planting and peaked at about 6 wk after planting, a time frame similar to that previously reported for imazethapyr and imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid} symptom development in cotton (York and Wilcut, 1993). Cotton stand was reduced by imazapic at 140 g ha^{-1} applied preplant incorporated and early postemergence (Table 1). Data to compare cotton emergence with plant survival were not collected. However, visual observations suggested cotton emergence was similar in all treatments. In other research (Basham et al., 1987), imazaquin at rates up to eight times the commercial use rate did not affect cotton emergence.

Greater boll production in 1992 was noted in plots previously treated with imazapic applied preplant incorporated at 140 g ha^{-1} (Table 1). However, plant mapping indicated delayed cotton reproductive development in these plots. In check plots, the first sympodium (fruiting branch) was on node six. Compared with the check, imazapic at 140 g ha^{-1} applied preplant incorporated to the preceding peanut crop reduced boll production from nodes six through 13 (Table 2).Injured cotton compensated for the delay in reproductive development by setting more bolls on sympodia from nodes 18 and higher. Similar effects of imazaquin residues were reported earlier (York and Wilcut, 1993). Other researchers also have reported cotton maturity delays due to

Table 1. Cotton cv. DES 119 injury, stand, boll production, and yield in 1992 following peanut treated with imazapic and imazethapyr in 1991 at the Upper Coastal Plain Research Station near Rocky Mount, NC.†

Herbicides	Rates	Method of application	Injury‡	Stand	Boll production	Seedcotton yield
	g ha^{-1}		%	No.(10 m)$^{-1}$	No.(10 plants)$^{-1}$	kg ha^{-1}
Imazapic	35	Preplant incorporated	0	123	118	3650
Imazapic	70	Preplant incorporated	19*	115	126	3150
Imazapic	140	Preplant incorporated	58*	106*	162*	2010*
Imazapic	35	Early postemergence	0	125	118	3890
Imazapic	70	Early postemergence	0	119	109	3830
Imazapic	140	Early postemergence	20*	106*	149	3360
Imazethapyr	70	Early postemergence	0	121	120	3860
Check	-	-	0	122	126	3590

† Means followed by an asterisk (*) are different from the check at P = 0.05.

‡ Injury recorded 6 wk after planting.

Table 2. Cotton cv. DES 119 boll distribution in 1992 following peanut treated with imazapic in 1991 at the Upper Coastal Plain Research Station near Rocky Mount, NC.†

	Nodes			
Treatments	6-9	10-13	14-17	> 17
	% of total bolls			
Check	28	33	22	11
Imazapic 140 g ha^{-1} applied preplant incorporated	15*	23*	23	34*

† Means followed by an asterisk (*) are different from the check at P = 0.05.

carryover of imidazolinone herbicides (Johnson and Talbert, 1996; Johnson et al., 1995). Boll weight was not determined, but the bolls in the upper portion of plants in plots previously treated with imazapic at 140 g ha^{-1} preplant incorporated appeared to be smaller. Additionally, many of these bolls never matured and opened. This lead to a 44% seedcotton yield reduction (Table 1). Other treatments had no effect on boll distribution in 1992 (data not shown).

Greater carryover of imidazolinone herbicides has been observed when the herbicides were applied preplant incorporated compared with preemergence or postemergence application (Curran et al., 1992; Johnson and Talbert, 1996; Renner et al., 1988). This carryover was likely due to less photolysis of the herbicides applied preplant incorporated (Basham and Lavy, 1987; Venkatesh et al., 1993). Photolysis may explain why less cotton injury was observed following early postemergence application of imazapic in 1991, compared with preplant incorporated application. Only 0.25 cm of rainfall was received during the first 20 d after early postemergence application in 1991 (data not shown). Imazapic applied early postemergence may have remained predominately on the soil surface where it could be subjected to photolysis while imazapic applied preplant incorporated may have been better protected from photolysis. Additionally, May, June, August, and October, 1991 were drier than normal (Table 3), perhaps reducing microbial degradation of imazapic. Average temperatures during the 1991 growing season were 0.3 to 3.3 °C greater than normal (data not shown), but these small differences likely would not affect herbicide dissipation.

Table 3. Monthly rainfall, 1991 to 1994, at Upper Coastal Plain Research Station near Rocky Mount, NC.†

Month	30-yr average	1991	1992	1993	1994
	cm				
January	9.90	8.95	14.35	10.95	7.10
February	9.80	1.75	6.30	6.45	6.75
March	10.50	10.85	9.05	16.50	19.35
April	8.15	7.30	5.25	8.30	4.25
May	9.90	4.70	5.50	6.25	8.15
June	11.10	3.35	14.40	6.60	11.45
July	12.40	19.55	7.20	11.40	9.65
August	12.10	8.852	9.70	2.40	10.90
September	9.60	10.80	8.25	12.15	9.25
October	7.15	4.95	9.75	10.55	7.10
November	7.05	6.00	14.80	8.30	4.25
December	8.45	8.95	6.95	11.75	2.50

† Rainfall recorded on site.

Cotton was injured 3% or less in 1993 and 1994 by imazethapyr at 70 g ha^{-1} applied early postemergence or imazapic at 70 g ha^{-1} applied postemergence to the preceding peanut crop (Table 4). At 140 g ha^{-1}, rates twice those recommended by the manufacturer, imazapic and imazethapyr injured cotton 10% or less. Neither herbicide applied to the

Table 4. Cotton cv. DES 119 injury and yield in 1993 and 1994 following peanut treated with imazapic and imazethapyr in the preceding year at the Upper Coastal Plain Research Station near Rocky Mount, NC.†

			Injury‡		
Herbicide	Rate	Method of application	1993	1994	Seedcotton yield§
	g ha^{-1}		%		kg ha^{-1}
Imazapic	35	Postemergence	0	1	2550
Imazapic	53	Postemergence	0	1	2650
Imazapic	70	Postemergence	1	3*	2640
Imazapic	105	Postemergence	3	9*	2570
Imazapic	140	Postemergence	4*	10*	2420
Imazethapyr	70	Early postemergence	1	0	2590
Imazethapyr	140	Early postemergence	9*	2	2470
Check	-	-	0	0	2540

† Means followed by an asterisk (*) are different from the check at P = 0.05. No differences were observed in seedcotton yields relative to the check.

‡ Injury recorded 6 wk after planting.

§ Yield pooled over years.

preceding peanut crop affected cotton stand or boll production (data not shown) or seedcotton yield in 1993 or 1994 (Table 4). Greater than normal rainfall was received during the 1992 growing season, but the 1993 season was drier than normal (Table 3).

Treatments had no effect on lint percentage or the fiber quality parameters recorded (data not shown). Pooled over treatments, lint percentage, micronaire, fiber length, fiber length uniformity, and fiber strength were 43.5%, 4.3, 29 mm, 82.4%, and 307 kN m kg^{-1}, respectively, in 1992; 43.4%, 4.8, 29 mm, 83.6%, and 313 kN m kg^{-1}, respectively, in 1993; and 41.6%, 5.3, 29 mm, 83.8%, and 279 kN m kg^{-1}, respectively, in 1994.

These results suggest there is minimal risk of imazethapyr carryover to cotton planted the year following postemergence application to peanut. Similar conclusions were reached by Johnson and Talbert (1996). Our results substantiate the manufacturer's recommendation (Pursuit DG Herbicide label, BASF Corp., Research Triangle Park, NC) that cotton can be planted 9.5 mo after postemergence application of imazethapyr if 41 cm or more of rainfall or irrigation are received between the time of imazethapyr application and the end of October of the application year. Our results also indicate little risk of imazapic carryover to cotton if the herbicide is applied postemergence. Imazapic carryover has been noted occasionally in growers' fields in North Carolina, whereas imazethapyr carryover has not been observed (authors' personal observations).

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