Chapter 6

THE BIOLOGY AND MANAGEMENT OF WEEDS IN PEANUT (*ARACHIS HYPOGAEA*)

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LOSSES AND COSTS DUE TO WEEDS

Weeds may reduce producers' income in several different ways. Herbicide costs range from $37 to $124/ha with a net cost to U.S. peanut producers in excess of $70 million annually (Table 1). Weeds also increase the need for additional primary and secondary tillage, i.e., with a net loss to producers of $7 to $20/ha. Weeds that escape control then cost producers another $49 to $124/ha due to yield reductions and $7 to $62/ha due to quality reductions (Bryson, 1989; Bridges, 1992). In Florida and Texas, land values are reduced where weeds are a major pest. Finally, harvesting efficiency is reduced and yield losses increased in harvesting weedy fields due to physical obstruction by weed biomass. This harvesting loss is estimated to range from $7/ha in Alabama to $17/ha in Oklahoma and South Carolina.

Estimated total income losses from control procedures for weeds, yield and quality reductions, increased cultural inputs, and reduced harvesting efficiency range from $132/ha in Texas to $391/ha in Florida. Total income loss for U.S. peanut producers was in excess of $105 million in 1988 (Bridges, 1992).

Interference and Competition

Interference is a term encompassing the overall effects of neighboring plants on the crop's growth (Harper, 1977; Zimdahl, 1980, 1988). Interference comprises the interactions from (a) competitive interference for growth factors including water, light, space, and inorganic nutrients; (b) allelochemical interference; (c) parasitic interference; and (d) indirect interference where a neighboring weed harbors insects, pathogenic microorganisms, etc. that attack the crop (Harper, 1977; Bendixen *et al.*, 1981; Zimdahl, 1988). As discussed above, weed interference reduces crop yield, quality, and harvesting efficiency.

Threshold Levels

The weed density at which potential economic losses in crop yield and quality exceed the cost of control and is economically justified, is called the economic threshold (Zimdahl, 1988; Brecke and Colvin, 1991). Early in the growing season, the weed populations usually are dense enough that some type of control procedure is justified. Later in the growing season after early postemergence (POST) herbicides have been applied, weed densities are

Table 1. Estimated cost of weed control and economics losses to peanut in 1988[a].

Category	Losses	Alabama	Florida	Georgia	N. Carolina	Oklahoma	S. Carolina	Texas	Virginia
Cost of herbicides	ha^{-}	96,356	35,628	279,352	58,704	36,437	5,668	101,215	39,676
	Cost/ha ($)	74	106	124	86	99	62	37	82
	Total value ($)	7,140,000	3,784,000	34,500,000	5,075,000	3,600,000	350,000	3,750,000	294,000
Loss in yield	ha	48,583	19,433	161,943	16,000	24,291	2,429	20,243	4,049
	Cost/ha ($)	111	124	99	99	124	49	49	49
	Total value ($)	5,400,000	2,400,000	16,000,000	1,600,000	3,000,000	120,000	1,000,000	200,000
Loss in quality	ha	24,291	8,907	40,486	4,049	24,291	2,429	20,243	4,049
	Cost/ha ($)	10	7	10	62	7	59	7	10
	Total value ($)	240,000	66,000	400,000	250,000	180,000	24,000	150,000	40,000
Loss in extra land preparation and cultivation	ha	85,020	27,530	279,352	12,146	36,437	5,668	40,486	20,243
	Cost/ha ($)	20	16	20	12	7	7	12	12
	Total value ($)	1,680,000	442,000	5,520,000	150,000	540,000	42,000	50,000	250,000
Loss in land value	ha^{-}	N/A	4,858	N/A	N/A	N/A	N/A	20,243	N/A
	Cost/ha ($)	N/A	124	N/A	N/A	N/A	N/A	12	N/A
	Total value ($)	N/A	600,000	N/A	N/A	N/A	N/A	250,000	N/A
Loss in increased cost of harvesting	ha	48,583	11,336	121,457	12,146	24,291	2,429	20,243	18,214
	Cost/ha ($)	7	14	12	12	17	17	15	10
	Total value ($)	360,000	154,000	1,500,000	150,000	420,000	42,000	300,000	180,000
	Total cost/ha ($)	96,356	35,628	279,352	58,704	36,437	5,668	N/A	39,676
	Total value $/ha	14,820,000	7,446,000	57,920,000	7,225,000	7,700,000	578,000	10,450,000	964,000

[a] Values and data are from Bryson (1989).

usually lower and economic thresholds may provide a basis for making a weed management decision. Only limited research has been conducted in this area with peanut and results often are inconsistent and vary with growing season, environmental conditions, and geographical location (Brecke and Colvin, 1991; Wilcut *et al.*, 1994c).

There is little research on the effect of sub-threshold weed levels on weed seed production, crop harvestability, and crop quality. In addition, the interactions of herbicide treatments, both soil and POST applied with thresholds has not been conducted. Residual herbicides that do not control, but suppress a weed may be affecting the competitiveness between the weed and the crop. Furthermore, while threshold and periods of critical interference may be known, the herbicide(s) registered may be restricted to very specific application timings due to crop safety and tolerance, post-harvest intervals required between application and harvest, and periods of effectiveness against the targeted weed populations. For example, POST herbicide treatments in peanut have historically been most peanut efficacious when applied approximately 2 to 3 wk after crop emergence (Wehtje *et al.*, 1986; Wilcut *et al.*, 1987b,c, 1989a, 1991a) with few exceptions (Wilcut *et al.*, 1991b). Paraquat can only be applied within 28 days after peanut emergence (DAE) (Anonymous, 1994). While chlorimuron cannot be applied within 60 DAE (Anonymous, 1994). In addition, 2,4-DB and chlorimuron cannot be applied within 45 days of peanut harvest (Anonymous, 1994). Peanut maintained weed-free for 4 to 6 weeks usually yield as well as totally weed-free peanut (Buchanan *et al.*, 1982; Brecke and Colvin, 1991).

Annual and perennial grasses are more competitive and detrimental to peanut yield than annual and perennial broadleaf weeds. As few as 0.2 fall panicum plants/m (common and scientific names and the Bayer Code for weed species discussed in this chapter are provided in Table 2) of row reduced yield 25% (York and Coble, 1977). Full-season interference from fall panicum in 1974 and 1975 reduced peanut yields 90 and 82%, respectively (York and Coble, 1977). Goosegrass densities of 0.2, 0.4, 0.8, 1.6, and 3.2 plants/m of row reduced peanut yields 2, 13, 15, 19, and 25%, respectively (McCarty and Coble, 1983). One goosegrass plant/m of row reduced peanut yield 4.1 kg/ha. In Oklahoma, a mixed population of crabgrass and smooth pigweed reduced peanut yield 95%, while full-season large crabgrass interference reduced peanut yield 25% (Hill and Santelman, 1969). Full-season interference from broadleaf signalgrass populations of 0.8, 1.6, and 105 plants/m row reduced peanut yield 14, 28, and 69%, respectively (Chamblee *et al.*, 1982b). Regression analyses showed that slightly less than 0.4 plants/m row significantly reduced peanut yield (Chamblee *et al.*, 1982b).

Peanut yield was reduced 20 to 40% by one Florida beggarweed plant/m of row (Buchanan *et al.*, 1982; Hauser *et al.*, 1982). In an area of influence study, individual plants of five Florida beggarweed biotypes reduced peanut yield in 1 m of row from 10 to 24% (Cardina and Brecke, 1989). The Florida beggarweed biotypes also differed in competitive ability.

In another study, percentage light attenuation as a function of Florida beggarweed canopy area was described by the equation:

Table 2. Common and Latin names of weeds ocurring in peanut fields.

Common name[a]	Latin name	Bayer code
Amaranth, palmer	*Amaranthus palmeri* S. Wats.	AMAPA
Anoda, spurred	*Anoda cristata* (L.) Schlecht.	ANVCR
Beggarweed, Florida	*Desmodium tortuosum* (S.W.) D.C.	DEDTO
Bermudagrass, common	*Cynodon dactylon* (L.) Pers.	CYNDA
Burgherkin	*Cucumis anguria* L.	CUMAN
Carpetweed	*Mollugo verticillata* L.	MOLVE
Cocklebur, common	*Xanthium strumarium L.*	XANST
Copperleaf, hophornbeam	*Acalypha ostryifolia* Riddell	ACCOS
Crabgrass, large	*Digitaria sanguinalis* (L.) Scop.	DIGSA
Crabgrass species	*Digitaria* spp.	DIGZZ
Crabgrass, southern	*Digitaria ciliaris* (Retz.) Koel.	DIGSP
Croton, tropic	*Croton glandulosus* Muell. Arg.	CVNGS
Crowfootgrass	*Dactyloctenium aegyptium* (L.) Wild.	DTTAE
Eclipta	*Eclipta alba* L.	ECLAL
Foxtail species	*Setaria* spp.	SETZZ
Goosegrass	*Eleusine indica* (L.) Gaertn.	ELEIN
Horsenettle, Carolina	*Solanum carolinense* L.	SOLCA
Horsenettle, robust	*Solanum dimidiatum* Raf.	SOLDM
Jimsonweed	*Datura stramonium* L.	DATST
Johnsongrass	*Sorghum halepense* (L.) Pers.	SORHA
Lambsquarters, common	*Chenopodium album* L.	CHEAL
Morningglory, entireleaf	*Ipomoea hederaceae* var. *integriuscula* Gray	IPOHG
Morningglory, ivyleaf	*Ipomoea hederacea* (L.) Jacq.	IPOHE
Morningglory, pitted	*Ipomoea lacunosa* L.	IPOLA
Morningglory, smallflower	*Jacquemontia tamnifolia* (L.) Griseb.	IAQTA
Morningglory, tall	*Ipomoea purpurea* (L.) Roth	PHBPU
Nightshade, silverleaf	*Solanum elaeagnifolium* Cav.	SOLEL
Nutsedge, purple	*Cyperus rotundus* L.	CYPES
Nutsedge, yellow	*Cyperus esculentus* L.	CYPRES
Panicum, fall	*Panicum dichotomiflorum* Mich.	PAQIN
Panicum, Texas	*Panicum texanum* Buckl.	PANTE
Passionflower, maypop	*Passiflora incarnata* L.	PAVIN
Pigweed	*Amaranthus* spp.	AMAZZ
Pigweed, redroot	*Amaranthus retroflexus* L.	AMARE
Pigweed, smooth	*Amaranthus hybridus* L.	AMACH
Poinsettia, wild	*Euphorbia heterophylla* L.	EPHHL
Purslane, common	*Portulaca oleracea* L.	POROL
Pusley, Florida	*Richardia scabra* L.	RCHSC
Ragweed, common	*Ambrosia artemisiifolia* L.	AMBEL
Sandbur	*Cenchrus* spp.	CENZZ
Sedges	*Cyperus* spp.	CYNZZ
Senna, coffee	*Cassia occidentalis* L.	CASOC
Sicklepod	*Senna obtusifolia* (L.) Irwin & Barneby	CASOB
Sida, prickly	*Sida spinosa* L.	SIDSP
Signalgrass, broadleaf	*Brachiaria platyphylla* (Griseb.) Nash.	BRAPP
Spurge, prostrate	*Euphorbia humistrata* Engelm. ex Gray	EPHHT
Spurge species	*Euphorbia* spp.	EPHZZ
Smartweed, Pennsylvania	*Polygonum pensylvanicum* L.	POLPY
Starbur, bristly	*Acanthospermum hispidum* DC.	ACNHI
Trumpetcreeper	*Campsis radicans* (L.) Seem. ex Bureau	CMIRA
Velvetleaf	*Abutilon theophrasti* Medicus	ABUTH

[a] Common names of weeds and Bayer codes are a WSSA-approved computer code from Composite List of Weeds, Rev. 1989. Available from WSSA, 1508 W. University, Champaign, IL 61821.

$$Y = \ln X / 25.5 \qquad \text{Eq. (1)}$$

where Y (% light attenuation) = natural log of X (% canopy cover of Florida beggarweed) divided by 25.2 (Cardina and Brecke, 1991). Peanut yield in this study was reduced 19% in 60 cm of row on either side of a single Florida beggarweed plant. In other research, full-season sicklepod interference reduced peanut yield 70%, while Florida beggarweed interference reduced yield 38% (Buchanan *et al.*, 1982).

Full-season interference from 1.1, 2.1, 4.3, and 8.5 bristly starbur plants/m of row reduced peanut yields 14, 26, 43, and 50%, respectively (Walker *et al.*, 1989). Full-season bristly starbur interference in Florida reduced yield up to 72% (England *et al.*, 1982).

Common cocklebur densities of 2, 4, and 8 plants/7.6 m of row reduced peanut yields by 15, 30, and 50%, respectively (Brecke and Royal, 1990). Common cocklebur at distances of 0 to 25 cm from peanut reduced yields 50% for the cultivars NC 7 and 30, 26, and 13% for the Florida breeding lines BL-10, BL-8, and F8143B, respectively (Fiebig *et al.*, 1991). Cocklebur plants 25 to 50 cm from peanut had less effect on peanut yields; F8143B was least affected, and NC 7 most affected. These data indicated that there is potential for developing peanut cultivars with improved competitive ability.

Wild poinsettia interference in Georgia peanut fields consistently reduced peanut yield at densities as low as 0.4 plants/m of row despite being mowed prior to digging (Bridges *et al.*, 1992). Peanut yield was reduced 30 to 50% at wild poinsettia densities of 3.2 plants/m of row. In Florida research, Royal *et al.* (1989) found that wild poinsettia reduced peanut yield an average of 11.8 kg/ha for each wild poinsettia plant/m of row.

In 1 of 2 years, spanish peanut yield was reduced 19% by horsenettle at 3.2 plants/m (Hackett *et al.*, 1987b). They concluded that horsenettle fruit contamination and reduced harvesting efficiency may be a greater problem with horsenettle interference than potential yield reduction.

Critical Periods of Weed Interference

The critical period of weed interference refers to the minimum amount of time during which the crop must be kept free of weeds in order to prevent yield loss (Zimdahl, 1988). This period has been determined for a number of weeds in peanut and can be used to optimize timing of weed control practices (Buchanan *et al.*, 1982). It represents the time interval falling between two separate components: (a) the minimum length of time after planting that a crop must be kept weed-free so that later-emerging weeds do not reduce yields and (b) the maximum length of time that weeds which emerge with the crop can remain before they become large enough to compete for growth resources (Weaver and Tan, 1983). The former relates to the required length of residual activity for a soil-applied herbicide and the latter to the optimal timing for postemergence weed control. Weeds which are present before or after this time interval generally do not affect yields. If these two components overlap, then there is no critical period and a single weed control operation should be sufficient (Weaver and Tan, 1983). Critical period studies are descriptive rather than predictive in nature, and the results will be affected by environmental conditions and the composition of the weed community.

Two types of studies are conducted to determine the critical period of interference. In the first type, the crop and weeds emerge together (Zimdahl, 1988). Weeds are allowed to grow for various time periods after which the crop is kept weed-free for the remainder of the growing season. In the second type, weeds are allowed to emerge at various times following crop emergence and are allowed to interfere with the crop until harvest.

Fall panicum interference for only the first 2 weeks after crop emergence reduced peanut yield 28% (York and Coble, 1977), whereas emergence 8 weeks after crop emergence reduced peanut yield 15%. Peanut yield was not reduced by smooth pigweed and large crabgrass that emerged 6 weeks after peanut planting nor when smooth pigweed and large crabgrass were removed within 3 weeks of planting (Hill and Santlemann, 1969). Broadleaf signalgrass interference with peanut for 6 weeks or less after planting did not reduce seed yields; interference for 8 weeks or longer after planting reduced yield 16% (Chamblee *et al.*, 1982b).

Peanut produced maximum yields when maintained free of Florida beggarweed and sicklepod for 4 weeks after crop emergence (Buchanan *et al.*, 1982). Florida beggarweed and sicklepod could also compete for up to 10 weeks after planting before peanut yields were reduced. A weed-free period of 4 to 6 weeks was required to eliminate peanut yield reductions from Florida beggarweed.

Yield of peanut maintained free of bristly starbur for 6 weeks after crop emergence was reduced by no more than 3% compared to peanut maintained weed-free for the entire season (Walker *et al.*, 1989). Bristly starbur interference for 2 weeks after crop emergence reduced peanut yield by an average of 4% over a 3-year period.

Peanut required a cocklebur-free period of 10 to 12 weeks to yield 90% of weed-free peanut (Fiebig *et al.*, 1991). Cocklebur interference for 2 to 4 weeks reduced peanut yields 8 and 16%, respectively.

Interference of several perennial broadleaf weeds to peanut in Oklahoma also has been investigated. Horsenettle may be tolerated for 6 to 8 weeks in runner-type peanut before any appreciable yield reduction occurs (Hackett *et al.*, 1987b). In addition, a spanish-type cultivar tolerated horsenettle interference for a longer duration than a runner-type cultivar.

Silverleaf nightshade, another perennial broadleaf weed species, reduced peanut yield 17% with 4 weeks of interference after planting (Hackett et al, 1987a). Peanut yield was reduced 53, 66, and 66% from 8 weeks, 12 weeks, and full-season interference. Each week during which peanut was maintained free of silverleaf nightshade increased peanut yield 33 to 38 kg/ha while each week of interference reduced yield 4.5%. Fruit contamination from full-season interference and 4 weeks of weed-free conditions was significant. Peanut yield did not differ with 4, 8, and 12 weeks of weed-free growth.

Peanut yield reductions occurred if wild poinsettia was allowed to interfere for more than 3 weeks after peanut emergence (Bridges *et al.*, 1992). To prevent yield reductions, wild poinsettia must be kept below 0.4 to 0.8 plants/m of row for at least 8 to 10 weeks after peanut emergence. Significant yield reductions occurred if wild poinsettia was allowed to grow with peanut for longer than 8 weeks in Florida (Royal *et al.*, 1989).

A model to predict peanut yield losses from different densities of broadleaf weed species is being developed (Barbour and Bridges, 1990, 1992). Their model is a sub-model that is integrated with the PNUTGRO model (Boote *et al.*, 1988). PNUTGRO is a physiologically-based model of peanut growth and development which incorporates environmental and genetic information (see Chapter 9). Light is a key input into PNUTGRO and is assumed to be the primary resource for which broadleaf weeds compete with peanut (Barbour and Bridges, 1990, 1992). Simulated weed populations of 1.65 weeds/m reduced yields 48% for Florida beggarweed, 22% for sicklepod, and 15% for wild poinsettia. Using light attenuation data for a weed specific profile has allowed for accurate predictions of yield reductions from broadleaf weed densities using historic data and in preliminary research. This model is being developed for common broadleaf weed species in peanut production and is being expanded to investigate the influence of water as a limiting factor in peanut-weed interactions (D. C. Bridges, pers. commun., 1992).

For peanut, it appears that a weed-free period of 4 to 6 weeks will prevent a significant reduction in yield (Buchanan *et al.*, 1982; Brecke and Colvin, 1991). Peanut will generally tolerate weed interference for 6 to 8 weeks without yield reductions. By comparison, soybean has a weed-free requirement of only 3 weeks and can tolerate weed interference for 8 to 9 weeks (Stoller *et al.*, 1987; Zimdahl, 1988).

Influence on Harvesting Efficiency

As previously mentioned, weeds can reduce harvesting efficiency and cost U.S. producers an estimated $3.0 million annually (Table 1). Weeds are particularly troublesome during digging and inverting procedures (Young *et al.*, 1982). Weed biomass slows field-drying of peanut vines and pods and increases the likelihood of exposure to rainfall which can increase harvesting losses (Young *et al.*, 1982; Wilcut *et al.*, 1994c). The fibrous root system of annual grasses is extremely difficult to separate from the peanut (Wilcut *et al.*, 1994c). During digging and combining operations, the peanut pods become detached from the peanut vines and are left on the soil surface. These detached peanut pods cannot be recovered with current mechanized harvesting equipment. No research has been conducted to quantify harvest losses due to weed interference, but general observations suggest this loss can be significant (Grichar, Wilcut, and A.C. York, pers. obs.).

INTERACTIONS OF WEEDS WITH OTHER PESTS

Plant Diseases

Weeds may serve as hosts for various plant pathogens which cause disease in peanuts (Manuel *et al.*, 1980). However, most plant pathologists and weed scientists believe that weeds primarily impact disease incidence by reducing the efficiency of foliar fungicide applications. Only limited research has been conducted in this area (Royal *et al.*, 1991).

In Florida, a density of one sicklepod plant/m of row reduced chlorothalonil (tetrachloroisophthalonitrile) deposition on peanut foliage by an average of 33% (Royal *et al.*, 1991). One Florida beggarweed plant/m of row intercepted 38% of the chlorothalonil in 1 year. In another year, 0.5 common cocklebur plant/m of row intercepted 59% of the chlorothalonil. Common cocklebur had more impact on the area under the disease progress curve than did Florida beggarweed or sicklepod.

Insects

Weeds are hosts to several insect species that are problems in peanut. These include tobacco thrips [*Frankliniella fusca* (Hinds)] and spider mites (*Tetranychus urtica* Koch). In Virginia, combined injury from tobacco thrips and acifluorfen (the common and chemical names for all herbicides discussed in this chapter are listed in Table 3) or paraquat applied POST significantly reduced peanut main stem height and canopy width compared with plants that were protected from thrips and not subjected to herbicide stress (Herbert *et al.*, 1991). Differences in peanut growth remained apparent as late as 59 days after treatment (DAT). Although injured plants achieved normal foliar growth by harvest, yield, and gross returns were significantly reduced. Highest yields were obtained when thrips were controlled and pyridate, a POST herbicide, which did not injure peanut foliage was used. In North Carolina, peanut yield reduction from a combination of thrips feeding and foliar injury from paraquat also has been observed (Blenk *et al.*, 1990).

Murdock *et al.* (1986) in South Carolina investigated the interactions of tobacco thrips control and herbicides on competition between large crabgrass biomass production, peanut yield, and herbicide applications. Their data indicated that tobacco thrips control reduced peanut foliar damage from this insect and promoted early season canopy development. However, the peanut competitiveness with large crabgrass was not influenced. Furthermore, peanut yield over a range of large crabgrass control levels was not influenced by tobacco thrips control.

In Virginia and northeastern North Carolina, the growing season is often only 1 to 3 weeks longer than the minimum time required for peanut to fully mature. The combination of thrips feeding and early season herbicide injury could reduce yield and reduce yield quality due to delayed maturity (Blenk *et al.*, 1990; Herbert *et al.*, 1991). In addition, delayed maturity may increase the potential for frost damage. Frost-damaged peanuts are sold for approximately 80% less than the normal market price (Davidson *et al.*, 1982).

WEED CONTROL METHODS AND TECHNOLOGY

General Methods

Several weed management methods in peanut are passive, i.e., they do not require the direct involvement of the grower. Examples would include the exclusion of potentially noxious weeds from other countries and states

Table 3. Common and chemical names of herbicides mentioned in text.

Common name	Chemical name
AC 263,222[a]	(±)-2,4,5-dihydro-4-methyl-4-(1-methylethyl)-5-OXO-1*H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid
Acifluorfen	5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid
Alachlor	2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)acetamide
Benefin	*N*-butyl-*N*-ethyl-2,6-dinitro-4-(trifluoromethyl)benzenamine
Bentazon	3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide
Chloramben[b]	3-amino-2,5-dichlorobenzoic acid
Chlorimuron	2-[[[[(4-chloro-6-methoxy-2 pyrimidinyl)amino]carbonyl]amino]sulfonyl] benzoic acid
Clethodim[a]	(E,E)-(±)-2-[1[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohoxen-1-one
Dinoseb[a]	2-(1-methylpropyl)-4,6-dinitrophenol
EPTC	*S*-ethyl dipropyl carbamothioate
Ethalfluralin	*N*-ethyl-*N*-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoro-methyl)benzenamine
Fenoxaprop	(±)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid
Imazethapyr	2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid
Lactofen[a]	(±)-2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoro-methyl)phenoxy]-2-nitrobenzoate
Metolachlor	2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methyl-ethyl)acetamide
Naptalam[b]	2-[(1-naphthalenylamino)carbonyl]benzoic acid
Norflurazon	4-chloro-5-(methylamino)-2-(3-trifluoromethyl)phenyl)-3(2*H*)-pyridazinone
Paraquat	1,1'-dimethyl-4,4'-bipyridinium ion
Pendimethalin	*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine
Pyridate	*O*-(6-chloro-3-phenyl-4-pyridazinyl]-*s*-octyl carbonthioate
Sethoxydim	2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one
Trifluralin	2,6-dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl)benzenamine
2,4-DB	4-(2,4-dichlorophenoxy)butanoic acid
Vernolate	*S*-propyl dipropylcarbamothioate

[a] Herbicides currently not registered for use in peanut.

[b] Herbicides that manufacturers are not re-registering for use in peanut.

through quarantine efforts and providing growers with certified weed-free seed. Cultural and chemical practices require direct involvement of the grower. Cleaning field equipment to prevent moving weed seed from one field to another field can help reduce the spread of weed seed.

Cultural Control

Cultural practices act to reduce weed competition. Some of the more subtle practices that are not unique to peanut include planting later to avoid problems, crop rotations, and controlling weeds in rotational crops (Buchanan *et al.*, 1982; Walker, 1982b; Linker and Coble, 1990). Some weeds that are difficult to manage in other crops, such as Texas panicum in corn, can be controlled effectively and economically in peanut (Wehtje *et al.*, 1986; Wilcut *et al.*, 1989a, 1994c). Likewise, weeds that are difficult to control in peanut can be controlled easily in other crops; such as Florida beggarweed in cotton. Manipulating row spacing and cultivation are used primarily for weed control.

Row Spacing. Any practice that enhances the opportunity for the crop to dominate the site is beneficial in weed management (Walker, 1982b). Manipulating row width allows the crop to become dominant. Row width historically was set by the minimum distance needed for the passage of draft animals. These distances were frequently carried over with minimal modification into mechanized production practices. It is intuitively obvious that reducing row spacing would reduce the amount of time required for the crop to "canopy over" row middles. A variation of this idea is two closely spaced rows (approximately 20 cm apart) centered on a traditional 91-cm spacing. This is commonly referred to as a twin-row pattern. Machinery currently adapted to 91-cm rows can be used in twin rows.

Most row spacing studies, with or without weed competition, have shown either no differences in peanut yield or only minor increases with reduced spacing (Buchanan and Hauser, 1980; Hauser and Buchanan, 1981; Wehtje *et al.*, 1984; Colvin *et al.*, 1985a, b). It has been suggested that narrow row patterns may serve to increase the crop's ability to compete with weeds such that herbicide inputs could be reduced relative to those required in traditionally spaced rows.

Weed fresh weights and peanut yields were compared for cultivar Florunner peanut grown in twin and standard row spacings with a series of weed control systems that ranged from no herbicide to herbicide intensive systems (Colvin *et al.*, 1985a). Reductions in Texas panicum biomass in the twin row spacing were evident in 2 of 3 years of the study. Comparable reductions in broadleaf weed biomass and peanut yield increases were sporadic. Yield improvement from the twin row pattern was most pronounced when weed competition was reduced to a minimum, i.e., when relatively intense herbicide programs were used. While the twin row pattern did tend to affect weed growth and peanut yield in a positive manner, it was not consistent and herbicide inputs could not be reduced. In Georgia, herbicide inputs could be reduced with narrow rows when weed populations were low (Cardina *et al.*, 1987). If weed populations were high, increased herbicide inputs were required to maintain profitability. Planting in narrow rows reduced the potential for cultivation as an early season control option and increased reliance on herbicides.

Cultivar Selection. Cultivar selection may affect peanut competitiveness with weeds. As previously mentioned, some cultivars and breeding lines were more tolerant to common cocklebur and horsenettle interference than were others (Hackett *et al.*, 1987b; Fiebig *et al.*, 1991). The development of more competitive cultivars could help reduce reliance on chemical control options. However, increased peanut competitiveness is usually the result of more photosynthate resource allocation to vegetative growth than to reproductive growth. As a result, delayed maturity of the peanut crop and potentially lower yield could result (Fiebig *et al.*, 1991). Cultivars with delayed maturity would not be feasible for peanut production areas with relatively short growing seasons like the Virginia-North Carolina region, northern Texas, or Oklahoma. More vine growth also may lead to more disease problems and difficulty in digging and harvesting operations (Henning *et al.*, 1982; Porter *et al.*, 1982; Young *et al.*, 1982).

Cultivation. Weeds may be cultivated after the success or failure of the preplant-incorporated (PPI), preemergence (PRE), and/or the early POST herbicide treatment has been assessed. Cultivation in peanut is considered to be a fairly exacting process. Cultivation should be done early (before mid-June or before peanut plants begin to canopy over row middles or not at all to avoid injury to peanut vines which can increase the incidence of soil-borne diseases (Buchanan *et al.*, 1982; Porter *et al.*, 1982; Wilcut *et al.*, 1994c). Even an early season cultivation can be damaging if not done properly. Many peanut pods are formed on the cotyledonary lateral branches. Movement of soil onto these branches and around the base of the plant causes physical damage and enhances development of stem and pod diseases (Porter *et al.*, 1982; Wilcut *et al.*, 1994c). For example, cultivation that is not precise and "non-dirting" (i.e., soil is not moved onto the peanut foliage) may increase the occurrence of *Sclerotium rolfsii* Sacc. (various common names include stem rot, white mold, and southern blight), and sclerotinia blight caused by *Sclerotinia minor* Jagger, and sometimes *Sclerotinia sclortiorum* (Lib.) de Bary (Porter *et al.*, 1982). These diseases can cause catastrophic yield reductions.

Cultivation is of primary benefit in controlling annual weed species (Bridges *et al.*, 1984; Wilcut *et al.*, 1987b,c, 1994c). Vegetative organs (such as rhizomes, stolons, tubers, etc.) of perennial broadleaf and grass weeds are frequently spread by cultivation (Wilcut *et al.*, 1994c). Perennials are not thoroughly uprooted by cultivation and the perennial may resprout from these vegetative organs.

Research has been conducted to determine weed management, peanut yield, and economic returns of weed management systems that included cultivation only, herbicides only, and a combination of herbicides with one or two timely cultivations (Bridges *et al.*, 1984; Wilcut *et al.*, 1987a,b). Cultivation or herbicides alone failed to provide adequate weed control or high peanut yield. Systems that used herbicides with cultivation provided the greatest levels of weed control, peanut yield, and net returns. Intensive cultivation, however, can also result in significant peanut yield reductions (Hauser *et al.*, 1974).

Florida beggarweed emergence in the field was associated primarily with recent rainfall events and secondarily with cultivation (Cardina and Hook, 1989). Peaks of Florida beggarweed emergence occurred in response to the first rainfall event after soil disturbance in almost every treatment. Subsequent rainfall events usually were followed by lower emergence peaks. The main influence of soil disturbance was in the number of seedlings emerging rather than the seasonal pattern of emergence. Generally the first flush of germination following cultivation represented up to 40% of the season's total emergence, especially when the soil was cultivated early in the season. Cultivation alone did not stimulate germination and emergence without post-tillage rainfall. Large rainfall events early in the season, especially after cultivation, should increase Florida beggarweed populations that must be controlled in infested peanut fields (Cardina and Hook, 1989).

Early emerging Florida beggarweed reduces peanut yield more than later germinating weeds (Buchanan *et al.*, 1982; Hauser *et al.*, 1982). The pattern of Florida beggarweed emergence in this research indicated that one or two timely cultivations or herbicide applications after early season heavy rainfall could potentially control a large proportion of the Florida beggarweed population. This emergence pattern of Florida beggarweed is collaborated by weed control research where one or two timely herbicide applications and/or cultivations usually result in yields equivalent to a hand-weeded weed-free check (Bridges *et al.*, 1984; Wilcut *et al.*, 1987a,b, 1989a, 1990c).

Reduced Tillage. Peanut has traditionally been grown in a well-prepared seedbed. Relatively little research has been conducted in peanut using minimum-tillage production practices compared with other agronomic crops (Worsham, 1985). Part of this lack of interest was due to a perceived need to moldboard plow to bury crop residues to reduce the possibility of disease problems (Buchanan *et al.*, 1982; Henning *et al.*, 1982; Colvin *et al.*, 1985b). Many producers and researchers also believe that a well-prepared seedbed is essential for high peanut yields. Minimum-tillage production of most agronomic crops has increased substantially. The major benefits from minimum-tillage systems are soil and moisture conservation. Additional benefits include lower fuel requirements and reduced labor and equipment inputs.

In the early 1980s weed management practices for minimum-tillage peanut were studied. Effective weed control and peanut yields equivalent to that in hand-weeded control plots with several herbicide programs were obtained in a minimum-tillage system in Alabama (Colvin *et al.*, 1985b). Yields were greatest in minimum-tillage systems when peanut was planted in modified twin 18-cm rows as compared with 91-cm rows. Similar results were observed for peanut grown using conventional tillage (Colvin *et al.*, 1985a).

An economic analysis comparing the conventional- and minimum-tillage systems was not included in the Alabama study (Colvin *et al.*, 1985b). In a subsequent study (Wilcut *et al.*, 1987a), two minimum-tillage herbicide systems provided equivalent control of Texas panicum and Florida beggarweed and higher yields and net returns than comparable conventional-tillage systems. Successful weed control, high yields, and high net returns in minimum-tillage systems required more herbicide inputs than in conventional-tillage systems. Lower costs associated with machinery and tillage operations in the minimum-tillage system offset the higher costs of herbicide inputs.

In a later study, acceptable weed control also was achieved with both conventional and minimum tillage systems with the minimum-tillage systems requiring more herbicide inputs (Wilcut *et al.*, 1990b). However, yield in the conventional tillage system exceeded that in the minimum tillage systems by

800 to 1900 kg/ha. Net returns were greater with the conventional systems but this could not be attributed to better weed control or fewer disease problems.

In Florida, the influence of various surface and subsurface tillage practices in both conventional and minimum tillage systems on peanut root growth and yield was examined (Colvin *et al.*, 1988). Peanut germinated and developed normally in no-tillage plots provided that some amount of subsurface tillage had occurred. Without surface or subsurface tillage, natural soil disturbance was insufficient to insure proper seed and soil contact or seed cover. Peanut yield in conventional tillage plots exceeded that of peanut without surface preparation by 330 kg/ha, suggesting that some surface tillage is needed for high peanut yields. The researchers concluded that a friable seedbed is needed for maximum peanut yield, especially in dry years and on sandy soils underlain by hard pans and having low water-holding capacity.

Colvin and Brecke (1988a) also investigated peanut cultivar response to conventional and minimum tillage production practices. In three locations over a 2-year period, differences between cultivars grown under the two tillage systems were minor. The results indicated that peanut yield and quality would be equal under conventional or minimum tillage production.

Grichar and Boswell (1987a) directly compared no-tillage, minimum tillage, and conventional tillage systems in Texas. Annual grass control was unsatisfactory in no-tillage production, but POST graminicides were not registered for use in peanut at that time. The authors noted that use of POST graminicides would reduce the likelihood of grass being a significant problem. However, soil compaction hindered harvesting operations and reduced yields. The yield reduction was proportional to the reduction in tillage. Peanut in the no-tillage and minimum tillage systems yielded 600 to 2400 kg/ha and 280 to 1300 kg/ha less than peanut in conventional tillage systems. Disease due to *S. rolfsii* was not affected by tillage systems. The authors concluded that consistently lower yields and reduced harvesting efficiency due to soil compaction are problems that must be resolved before no-tillage production is practical.

Most studies concerning minimum tillage peanut production were conducted within the last decade. However, the herbicides registered for use in peanut have changed greatly since most of these studies were conducted. New research with herbicides registered since that time is needed. Still, most researchers believe that the likelihood of reduced and inconsistent yield with minimum tillage production does not result from poor weed control or increased disease incidence (Colvin *et al.*, 1985b, 1988; Grichar and Boswell, 1987a; Wilcut *et al.*, 1987a, 1990b; Colvin and Brecke, 1988a). Rather, it was the subtle additional benefits of tillage—i.e., improved seedling performance and ease of pegging and harvesting operations—that provided the consistently better yields in conventional tillage systems.

Biological Control

Biological weed control generally employs insects, plant pathogens, or nematodes (Cardina *et al.*, 1988; Brecke and Colvin, 1991; Cardina and

Brecke, 1991). Biological weed control has had little, if any, commercial success in peanut (Buchanan *et al.*, 1982; Brecke and Colvin, 1991; Wilcut *et al.*, 1994c) because most biological control agents are usually effective on only one weed species (Brecke and Colvin, 1991; Wilcut *et al.*, 1994c). Most peanut acreage is infested with at least several weed species at densities exceeding economic thresholds. *Curvularia bannonii* Morgan-Jones, a fungal leaf pathogen of smallflower morningglory, was greater than 85% effective when >10^5 spores/mL were dispersed in 1870 L/ha with a nonionic surfactant (Riley and Bannon, 1989). However, a dew period of 8 to 12 hours at 30 to 35 C was required for optimum infection. Smallflower morningglory was susceptible from the cotyledon to four-leaf growth stage. Pitted and ivyleaf morningglory were resistant, as were cotton, peanut, soybean, and sweet potato [*Ipomoea batatas* (L.) Lam.]. Sweet corn was more susceptible than field corn. Biological control agents for cocklebur (Quimby, 1989), goosegrass (Figliola *et al.*, 1988), and pigweed and morningglory species also are being investigated (Charudattan and DeLoach, 1988).

Alternaria cassia Jurair and Khan has potential for sicklepod control (Walker, 1982a; Walker and Riley, 1982). Control, however, was erratic (40 to 100%) and required an 8-hour dew period for maximum effectiveness. *Pseudocercospora nigricans* (Cooke) Deighton also has shown some potential for sicklepod control (Hofmeister and Charudattan, 1987).

Purple nutsedge can be suppressed by the insect *Bactra verutana* Zeller (Frick and Chandler, 1978). However, the insect cannot be stored for long periods of time and is expensive to rear. Considerable effort is under way in Georgia to develop the rust fungus [*Puccinia canaliculata* (Schw.) Lagerh.] for control of nutsedge species (Callaway *et al.*, 1985). However, nutsedge biotypes exhibit a differential response to this fungus (S. Phatak, pers. commun., 1992). Additionally, the fungus is sensitive to fungicides commonly used for control of fungal pathogens in peanut (S. Phatak, pers. commun., 1992). *Puccinia canaliculata* also has controlled yellow nutsedge in soybean plots in Florida and controlled purple nutsedge in greenhouse studies (Callaway *et al.*, 1985).

Colletotrichum truncatum (Schw.) Andrus and Moore controlled cotyledonary Florida beggarweed but required a relatively long dew period for maximum effectiveness (Cardina *et al.*, 1988). The parasitic nematode *Orrina phyllobia* (Thorne) Brzesk. has provided some control of silverleaf nightshade.

Biological control options may eventually provide commercial alternatives to herbicides and may supplement existing weed management programs (Cardina and Brecke, 1989; Brecke and Colvin, 1991). Currently, no biological control agent has provided weed control as consistent and efficacious under a wide variety of environmental conditions as chemical and mechanical control options. However, biological control agents could be successful for control of troublesome weed species for which there are no adequate chemical or cultural control options (Brecke and Colvin, 1991; Wilcut *et al.*, 1994c). For example, perennial broadleaf weed species currently cannot be controlled in peanut.

HISTORICAL DEVELOPMENT OF CHEMICAL WEED CONTROL IN PEANUTS

The historical development of weed control in peanut has been reviewed previously through 1982 (Hauser *et al.*, 1973; Buchanan *et al.*, 1982). Except for a brief overview, we will not duplicate this information. Rather, we will discuss new developments in peanut weed control since that time.

Chemical weed control in peanut began around 1949 (Hauser *et al.*, 1973; Buchanan *et al.*, 1982). Many new developments helped to revolutionize weed control in peanut between 1949 and 1982. By the mid-1980s, many peanut producers were using PPI applications of the dinitroaniline herbicides benefin, pendimethalin, and trifluralin (trifluralin used only in Texas and Oklahoma) or alachlor and metolachlor for annual grass and small-seeded broadleaf weed control (Hauser *et al.*, 1973; Buchanan *et al.*, 1982; Bridges *et al.*, 1984; Wilcut *et al.*, 1987b,c, 1994c; Brecke and Colvin, 1991). Alachlor and metolachlor also were being applied PRE for annual grass and small-seeded broadleaf weed control (Buchanan *et al.*, 1982; Bridges *et al.*, 1984; Wilcut *et al.*, 1994c).

Vernolate applied PPI was the only herbicide available to control both yellow and purple nutsedge (Buchanan *et al.*, 1982; Wilcut *et al.*, 1994c). Yellow nutsedge control was also obtained with PPI and PRE applications of alachlor and metolachlor or with POST application(s) of bentazon (Wilcut *et al.*, 1994c).

Broadleaf weeds were controlled with POST herbicides dinoseb, acifluorfen, bentazon, chloramben, and 2,4-DB (Buchanan *et al.*, 1982; Wehtje and Reed, 1985; Brecke and Colvin, 1991; Wilcut *et al.*, 1994c). Dinoseb was among the most popular and commonly used POST peanut herbicide in the early to mid-1980s (Buchanan *et al.*, 1982; Wilcut *et al.*, 1989a, 1994c).

Herbicide Registrations Since 1982

Sethoxydim, registered for use in peanut in 1985, was the first herbicide for POST control of annual and perennial grass species. Grasses are generally considered to be more competitive with peanut than broadleaf weeds or nutsedge species (Brecke and Colvin, 1991; Wilcut *et al.*, 1994c). Sethoxydim allows control of annual grasses that escaped PPI or PRE herbicides (Grichar and Boswell, 1986, 1987b; Wilcut *et al.*, 1987b, 1990b; Grichar, 1991a,b). Although dinoseb controlled some small annual grass species (Buchanan *et al.*, 1982), much larger annual grasses were controlled with sethoxydim (Grichar and Boswell, 1986, 1987b; Wilcut *et al.*, 1987a, 1990b, 1991c). Registration of sethoxydim was particularly significant in that it was the first herbicide available for control of the perennial grasses, common bermudagrass and johnsongrass (Grichar and Boswell, 1989; Wilcut, 1991b; Wilcut *et al.*, 1994c). Another POST graminicide, fenoxaprop, was registered for use in peanut in 1988. It controls many annual grasses and johnsongrass (Grichar and Boswell, 1989; Anonymous, 1994) but does not control common bermudagrass (Wilcut *et al.*, 1994c).

Ethalfluralin, a dinitroaniline herbicide, was registered for use in peanut in 1988. Ethalfluralin controls a weed spectrum similar to the other dinitroaniline herbicides benefin, pendimethalin, and trifluralin (Wilcut *et al.*, 1994c).

One of the most significant events in peanut weed control since the 1982 review was the decision by the U.S. Environmental Protection Agency (EPA) to cancel all dinoseb registrations in 1986. This decision was based upon new toxicological information (Anonymous, 1986). This cancellation removed the most economical, widely used, and efficacious broadleaf weed-controlling herbicide in the Southeast and Virginia-North Carolina peanut production areas (Buchanan *et al.*, 1982; Wilcut *et al.*, 1987c, 1989a). Cancellation encouraged development and registration of safer herbicides (chlorimuron, imazethapyr, norflurazon, paraquat, and pyridate) for peanut that may not have become available had dinoseb remained on the market.

Chlorimuron, a sulfonylurea herbicide (Beyer *et al.*, 1988), was registered for use in peanut in 1988. Chlorimuron provided good control of several broadleaf weeds including Florida beggarweed and sicklepod (Sims *et al.*, 1987). Peanut tolerance of early POST applications of chlorimuron was marginal. Tolerance increased with later applications, and research across the Southeast soon confirmed that chlorimuron applied 60 DAE did not reduce peanut yields (Colvin and Brecke, 1988b; Hammes *et al.*, 1990). Peanut tolerance of late POST applications of chlorimuron was due to less absorption and translocation and increased metabolism of chlorimuron (Wilcut *et al.*, 1989b). Chlorimuron is primarily used for late season control of escaped Florida beggarweed (Wehtje *et al.*, 1994c).

Imazethapyr, an imidazolinone herbicide, was registered for use in peanut in May 1991 and can be applied PPI, PRE, ground-cracking (GC), or POST. It was the first herbicide in peanut to provide residual control of purple and yellow nutsedge and numerous broadleaf weed species (Grichar *et al.*, 1990, 1992; Wilcut *et al.*, 1991a, 1992a, 1994a,b; Wiley *et al.*, 1991; Richburg *et al.*, 1993, 1995c,d,f; York *et al.*, 1995). Imazethapyr does not control common ragweed, common lambsquarters, tropic croton, Florida beggarweed, or sicklepod (Wilcut *et al.*, 1991c, 1992a, 1994c; York *et al.*, 1991; Richburg *et al.*, 1995c). In addition, many peanut producers are unaccustomed to rotational crop restrictions after imazethapyr application (Wilcut *et al.*, 1994c; York and Wilcut, 1995).

Norflurazon was registered for peanut in the summer of 1993. Norflurazon provides residual control of Florida beggarweed, prickly sida, spurred anoda, and tropic croton and some suppression of *Ipomoea* morningglory species, sicklepod, and yellow nutsedge (Wilcut *et al.*, 1993a, 1994c; McLean *et al.*, 1994b, 1995). It is primarily used for Florida beggarweed control in the Southeast and is the only currently registered herbicide to provide residual control of this troublesome weed. It is currently restricted to use only on runner peanut types. However, research has indicated no problem with norflurazon use on virginia-type peanut in the Southeast (McLean *et al.*, 1994a).

Pate (1978) and Buchanan and Bryant (1980) indicated that peanut was tolerant of paraquat, a herbicide previously considered to be relatively nonselective. In the early 1980's, Wehtje *et al.* (1986) examined a variety of timings and rates of paraquat application to determine the system for Texas panicum control (sethoxydim was not registered at that time) with minimal crop injury. Other studies were conducted to determine the maximum rate and timing of paraquat applications which peanut would tolerate (Brecke and Colvin, 1988). Tolerance was acceptable with maximum paraquat rates of 0.14 kg ae/ha. Peanut tolerates two paraquat applications if the crop has recovered from the first application before the second application is made, and if the second application is made no later than 28 DAE. Paraquat was registered for peanut in early 1988.

Further research demonstrated that paraquat provided control of several common and troublesome broadleaf weeds in the Southeast including sicklepod, Florida beggarweed, and *Ipomoea* morningglory species (Wilcut *et al.*, 1989a, 1990b,c; Wilcut and Swann, 1990). While paraquat controls sicklepod and Florida beggarweed, it does not control bristly starbur, coffee senna, prickly sida, and smallflower morningglory (Wilcut *et al.*, 1994a,c). However, mixtures of paraquat and bentazon control a broad spectrum of broadleaf weeds, such as bristly starbur, coffee senna, Florida beggarweed, prickly sida, and smallflower morningglory (Evans *et al.*, 1988; Wilcut 1991a; Wilcut *et al.*, 1992a, 1994c). In addition, foliar injury from paraquat is reduced with a paraquat plus bentazon mixture (Wehtje *et al.*, 1992a). Bentazon plus paraquat mixtures are now the standard program for broadleaf weed control in the Southeast (Wilcut *et al.*, 1994c). Paraquat has never gained acceptance in the southwestern area because of peanut injury from paraquat applied during hotter periods of the year and the lack of producer acceptance of any type of peanut injury (W.J. Grichar, pers. obs., 1994).

Pyridate, a POST herbicide, was registered in peanut in October 1992 for annual broadleaf weed control. Peanut has excellent tolerance of pyridate (Hicks *et al.*, 1990). It controls *Amaranthus* species, bristly starbur, common cocklebur, Florida beggarweed, prickly sida, and spurred anoda (Hicks *et al.*, 1990; Linker and Coble, 1990; Wilcut *et al.*, 1992a, 1994c). Pyridate will also control or suppress yellow nutsedge, however, multiple applications generally are required for adequate control (Grichar, 1992). It is a contact herb-icide providing no residual control and should be mixed with 2,4-DB to increase the spectrum and consistency of broadleaf weed control, especially for common cocklebur, eclipta, *Ipomoea* morningglory species, and sicklepod.

Weed Management With Herbicides

Relative to many other crops, peanut presents several unique features that must be taken into consideration in developing herbicide-based weed management systems. First, peanut requires a fairly long growing season; approximately 140 to 160 days, depending on cultivar and geographical region (Henning, *et al.*, 1982; Wilcut *et al.*, 1994c). A long growing season allows more time for weed problems to develop. Secondly, peanut has a prostrate grow habit and a relatively shallow canopy that is slow to shade row middles which allows weeds to be more competitive (Walker *et al.*, 1989;

Wilcut *et al.*, 1994c). Additionally, the fruit develops underground on pegs which originate from the stems that grow parallel to the soil surface. Thus, herbicides cannot be applied to the base of the plant, in contrast to more upright crops such as cotton and corn (Brecke and Colvin, 1991; Wilcut *et al.*, 1994c). Also, the prostrate growth habit and pattern of fruit development restricts cultivation to an early season control option only (Buchanan *et al.*, 1982; Brecke and Colvin, 1991; Wilcut *et al.*, 1994c).

The weed flora plaguing the three geographical areas of peanut production in the U.S. is diverse and consists of annuals and perennials of grasses, broadleaves, and sedges (Dowler, 1992) (Tables 4 and 5). Some weeds are extremely competitive while others are not. For the most part, grass species are most competitive and detrimental to peanut yields (see earlier section on weed competition). Nutsedge species are less competitive (J.W. Wilcut, unpubl. data, 1994), but nutsedge tubers are difficult to separate from peanut and increase foreign matter content (Young *et al.*, 1982). The resulting increased foreign matter content reduces peanut quality and profits for producers.

Soil-Applied Herbicides. Herbicides can first be applied to the soil

Table 4. Most common weed species in peanut, listed in order of prevalence, in eight U.S. peanut-producing states.

Alabama	Florida	Georgia	North Carolina
Fla. beggarweed	Crabgrass spp.	Fla. beggarweed	Broadl. signalgrass
Texas panicum	Fla. beggarweed	Texas panicum	Large crabgrass
Sicklepod	Sicklepod	Sicklepod	Prickly sida
Morningglories	Fla. pusley	Yellow nutsedge	Morningglory spp.
Nutsedge spp.	Pigweed spp.	Common cocklebur	Nutsedge spp.
Bristly starbur	Morningglory spp.	Sm.fl. morningglory	Common ragweed
Pigweed spp.	Nutsedge spp.	Coffee senna	Com. lambsquarters
Broadl. signalgrass	Goosegrass	Bristly starbur	Fall panicum
Crabgrass spp.	Sandbur spp.	Pitted morningglory	Pigweed spp.
Com. cocklebur	Texas panicum	Tropic croton	Common cocklebur
Oklahoma	South Carolina	Texas	Virginia
Crabgrass spp.	Crabgrass spp.	Texas panicum	Morningglory spp.
Pigweed spp.	Pigweed spp.	Palmer amaranth	Common cocklebur
Morningglory spp.	Goosegrass	Sandhills amaranth	Com. lambsquarters
Texas panicum	Sicklepod	Yellow nutsedge	Pigweed spp.
Johnsongrass	Nutsedge spp.	Broadl. signalgrass	Common ragweed
Yellow nutsedge	Morningglory spp.	Large crabgrass	Spurred anoda
Prickly sida	Common cocklebur	Ivyleaf morningglory	Crabgrass spp.
Hophornbeam copperleaf	Fla. beggarweed	Jungle rice	Prickly sida
Horsenettle	Texas panicum	Purslane	Yellow nutsedge
Spurge spp.	Tropic croton	Eclipta	

Table 5. Most troublesome weed species in peanut, listed in order of prevalence, in eight U.S. peanut-producing states.

Alabama	Florida	Georgia	North Carolina
Fla. beggarweed	Fla. beggarweed	Fla. beggarweed	Eclipta
Sicklepod	Sicklepod	Texas panicum	Broadl. signalgrass
Bristly starbur	Nutsedge spp.	Sicklepod	Fall panicum
Nutsedge spp.	Bristly starbur	Yellow nutsedge	Nutsedge spp.
Horsenettle	Morningglory spp.	Sm.fl. morningglory	Prickly sida
Texas panicum	Common cocklebur	Common cocklebur	Horsenettle
Citron melon	Pigweed spp.	Tropic croton	Com. lambsquarters
Burgherkin	Texas panicum	Bristly starbur	Texas panicum
Pigweed spp.	Goosegrass	Pitted morningglory	Citron melon
Maypop passion flower	Sandbur spp.	Coffee senna	Fla. beggarweed

Oklahoma	South Carolina	Texas	Virginia
Horsenettle	Fla. beggarweed	Yellow nutsedge	Com. bermudagrass
Yellow nutsedge	Sicklepod	Ivyleaf morningglory	Prickly sida
Hophornbeam copperleaf	Broadl. signalgrass	Woolly croton	Spurred anoda
Prickly sida	Morningglory spp.	Sandhills amaranth	Com. lambsquarters
Spurge spp.	Nutsedge spp.	Tumble pigweed	Morningglory spp.
Croton spp.	Pigweed spp.	Crownbeard	Common ragweed
Texas panicum	Texas panicum	Texas panicum	Johnsongrass
Johnsongrass	Johnsongrass	Hophorn beam copperleaf	Common cocklebur
Com. bermudagrass	Common ragweed	Prostrate spurge	Jungle rice
Eclipta	Tropic croton	Yellow nutsedge	Crabgrass spp.

either before or immediately after peanut planting. The intent is to prevent weeds from ever becoming established. Herbicide(s) from five classes are used in this way: (a) the dinitroaniline herbicides (benefin, ethalfluralin, pendimethalin, and trifluralin), (b) the chloroacetamide herbicides (alachlor and metolachlor), (c) a thiocarbamate herbicide (vernolate), (d) an imidazolinone herbicide (imazethapyr), and (e) norflurazon.

The dinitroaniline herbicides all have minimal water solubilities—i.e., less than 1 ppm (Humburg, 1989; Weber, 1990). In addition, some but not all are moderately volatile. Herbicide incorporation into the soil is required to prevent excessive volatilization which would result in reduced weed control. It is recommended that benefin, ethalfluralin, pendimethalin, and trifluralin be incorporated within 8 hours, 48 hours, 7 days, and 24 hours, respectively, after application (Anonymous, 1994).

Dinitroaniline herbicides control annual grasses including broadleaf signalgrass, crowfootgrass, *Digitaria* species, goosegrass, fall panicum, and Texas panicum and small-seeded broadleaf weeds such as Florida pusley, common lambsquarters, and *Amaranthus* species (Buchanan *et al.*, 1982; Chamblee *et al.*, 1982a; Wilcut *et al.*, 1994c). The dinitroaniline herbicides are the only soil-applied herbicides registered for use in peanut that will provide full-season control of Texas panicum (Wilcut *et al.*, 1987b,c). Dinitroaniline herbicides do not adequately control large-seeded broadleaf weeds (Wilcut *et al.*, 1994c).

Alachlor and metolachlor are the chloroacetamide herbicides registered for use in peanut. They control annual grasses, except Texas panicum and shattercane, and control small-seeded broadleaf weeds such as Florida pusley and pigweed species and yellow nutsedge (Buchanan *et al.*, 1982; Chamblee *et al.*, 1982a; Wilcut *et al.*, 1994c). They also suppress large-seeded broadleaf species including common ragweed, Florida beggarweed, bristly starbur, and sicklepod (Colvin *et al.*, 1990; Wilcut *et al.*, 1994c). Alachlor suppresses broadleaf weeds better than metolachlor, while metolachlor provides better yellow nutsedge control (Wilcut *et al.*, 1994c). The chloroacetamide herbicides can be applied either PPI, PRE, or GC (Anonymous, 1994).

The chloroacetamide herbicides are commonly used at rates of 2.2 to 5.6 kg/ai ha for annual grass and yellow nutsedge control, and suppression of large-seeded broadleaf weeds (Chamblee *et al.*, 1982a; Brecke and Colvin, 1991; Anonymous, 1994; Wilcut *et al.*, 1994c). Suppression of large-seeded broadleaf weeds was perceived as critical for successful weed management since no herbicide prior to registration of imazethapyr in 1991 provided residual control of large-seeded broadleaf weeds (Brecke and Colvin, 1991; Wilcut *et al.*, 1994c). All POST herbicides available for use prior to imazethapyr registration provided no appreciable soil activity. Chlorimuron also has soil residual activity but, when applied 60 DAE, it is primarily provides POST control of Florida beggarweed (Wehtje *et al.*, 1993; Wilcut *et al.*, 1994c).

Yellow nutsedge can be controlled with PPI or PRE alachlor, metolachlor, and imazethapyr (Grichar *et al.*, 1990, 1991; Brecke and Colvin, 1991; Grichar 1992; Richburg *et al.*, 1993, 1995c; Wilcut *et al.*, 1994c). Metolachlor provides better and more consistent yellow nutsedge control as a PPI application than as a PRE application (J.W. Wilcut and A.C. York, pers. obs., 1992). In the Southwest, metolachlor applied POST to yellow nutsedge and followed with irrigation has provided good to excellent control (Grichar *et al.*, 1991). The low humidity of the southwest region may allow metolachlor to be absorbed and translocated in the transpirational stream following irrigation.

Metolachlor and imazethapyr are considered to be the most effective soil-applied treatment for yellow nutsedge (Wilcut *et al.*, 1994c). Greenhouse research indicates that soil applications of imazethapyr are critical for successful yellow nutsedge control (Richburg *et al.*, 1993). Some research has indicated that PPI plus GC imazethapyr provides better control than any single application method (A.C. York, unpubl. data, 1993).

The use of both alachlor and metolachlor during this past decade has not been without controversy. Sporadic peanut injury attributed to metolachlor has been observed by growers and extension personnel in the southeastern region, Virginia, and in Texas (Cardina and Swann, 1988; Wehtje *et al.*, 1988; W.J. Grichar, unpubl. data, 1993). In these instances, peanut emergence and seedling growth were delayed and severely injured peanut may fail to emerge from the soil. Cardina and Swann (1988) examined growth and yield of peanut as influenced by PPI applications of metolachlor at 2.2 to 6.7 kg/ha at two Georgia locations on Tifton loamy sands (fine-loamy, siliceous, thermic Plinthic Paleudults) containing less than 1% organic matter and a pH of 6.0 and 6.2. Metolachlor delayed peanut emergence and reduced peanut growth when irrigation followed planting. In 1 year of the study at one location, irrigated peanut yielded less than nonirrigated peanut only when metolachlor was applied at 6.7 kg/ha, a rate well above the registered use rate (Anonymous, 1994).

Both alachlor and metolachlor applied at both registered and excessive rates were investigated in field studies in Alabama (Wehtje *et al.*, 1988). Across the 3 years of study, at least a twofold safety factor existed between the maximum registered rate and the one necessary for peanut injury. In 1 year of the study, metolachlor at 9.0 kg/ha and alachlor at 13.4 kg/ha reduced yields.

Laboratory studies on behavior of the two herbicides in soil was conducted also. Metolachlor was slightly more mobile than alachlor in soil chromatography experiments. Metolachlor may have a slightly greater propensity to damage peanut under conditions of extensive leaching and/or slow peanut emergence. Additionally, peanut is more tolerant of alachlor than metolachlor. However, in 12 years of field trials in North Carolina (A.C. York, unpubl. data, 1994) and 7 years of field trials in Virginia and Georgia (J.W. Wilcut, unpubl. data, 1994) peanut has never been injured from alachlor or metolachlor, including metolachlor applied 2.2 kg/ha applied PPI followed by 2.2 kg/ha applied GC.

In late 1990, a new class of metabolites of alachlor [2-ethyl-6-(1-hydroxyethyl)aniline, several compounds comprise this group] was detected in peanut (C. S. Kvien, pers. commun., 1991). This metabolite group, together with the other known metabolite group increased the likelihood that peanut treated with alachlor according to registered directions would have residues above tolerances established by the EPA. As a result, many peanut shellers and processors refused to buy alachlor-treated peanut in the 1991 growing season. Prior to this action, alachlor was estimated to be applied on approximately 48% of the U.S. peanut hectarage (Gianessi and Ruffer, 1990; Bridges, 1992).

Virginia-North Carolina growers experienced little difficulty in substituting metolachlor for alachlor (A.C. York, pers. obs., 1992). In the Southeast, the exclusion of alachlor from peanut weed management systems made the control of Florida beggarweed more difficult. Alachlor provided early season suppression of Florida beggarweed (Colvin *et al.*, 1990; Wilcut *et al.*, 1994c) until peanut was old enough to tolerate chlorimuron late-POST. Paraquat provides early season Florida beggarweed control (paraquat can be applied no later than 28 DAE) but provides no residual control (Wilcut *et al.*, 1989a, 1994c). Without the early season residual suppression from alachlor, Florida beggarweed often becomes too large for effective control with chlorimuron (J.W. Wilcut, pers. obs., 1994).

Vernolate is the only thiocarbamate herbicide registered for use in peanut. It is extremely volatile and it should be immediately incorporated into the soil to prevent loss (Anonymous, 1994). It frequently is mixed with a dinitroaniline herbicide and controls annual grasses, except Texas panicum, and also controls small-seeded broadleaf weeds such as common lambsquarters, Florida pusley, and pigweed species (Wilcut and Swann, 1990; Wilcut *et al.*, 1994c). Vernolate provides about 4 to 6 weeks of control, but not acceptable season-long control and is primarily used for yellow and purple nutsedge control. Until imazethapyr was registered in 1991, vernolate was the only herbicide registered for purple nutsedge control in peanut.

Thiocarbamate herbicides like vernolate can reduce leaf cuticle formation (Wilkinson, 1988). Wilkinson and Hardcastle (1969) found that cuticle thickness of sicklepod was decreased 35% on the petiole and 15% on the upper leaf surface by EPTC. As a result, POST herbicides may work more effectively on some weeds (Sherman *et al.*, 1983). For example, burgherkin control with alachlor plus naptalam plus dinoseb applied GC was improved when vernolate was applied PPI (Buchanan *et al.*, 1981). In Virginia, sequential applications of paraquat provided better common ragweed control when vernolate was applied PPI than without vernolate PPI (Wilcut and Swann, 1990). Unfortunately, peanut yield was also reduced when vernolate was applied PPI and followed with sequential applications of paraquat.

Imazethapyr, an imidazolinone herbicide, may be applied PPI, PRE, GC, or POST (Wilcut *et al.*, 1991a,b). Split applications of imazethapyr also may be used, with half of the rate applied PPI or PRE and half applied early POST. Imazethapyr applied PPI or PRE controls many troublesome weeds such as coffee senna, common lambsquarters, smallflower morningglory species, *Amaranthus* species including Palmer amaranth, prickly sida, purple and yellow nutsedge, spurred anoda, and wild poinsettia (Cole *et al.*, 1989; Wilcut *et al.*, 1991a,b; Grichar *et al.*, 1992; York *et al.*, 1995). Common lambsquarters control is better and more consistent with PPI or PRE applications; POST applications usually provide poor control. Split applications as PPI or PRE applications followed by a GC application are also very effective for the aforementioned weed species. Control of most species is better and more consistent with soil applications or a GC application on very small weeds (generally less than 3 cm tall).

Common ragweed and sicklepod control from imazethapyr was unacceptable (Wilcut, 1991a; Wilcut *et al.*, 1994a; York *et al.*, 1995), and tropic croton and Florida beggarweed escaped control (Wilcut, 1991c; Wilcut *et al.*, 1994a,b; Richburg *et al.*, 1995c). In the Southwest, imazethapyr was unacceptable for eclipta and hophornbeam copperleaf control (J. R. Sholar, pers. commun., 1992). Nutsedge control in the Southwest was inconsistent with imazethapyr applied PRE (Grichar *et al.*, 1992). The addition of metolachlor to imazethapyr improved yellow nutsedge control but not purple nutsedge control.

Imazethapyr can be applied PPI, PRE, GC, POST, or PPI plus GC for control of purple nutsedge (Grichar *et al.*, 1990, 1992; Wilcut 1991c; Wiley *et al.*, 1991; Richburg *et al.*, 1993). Imazethapyr is the only herbicide registered for use in peanut for POST control of purple nutsedge (Anonymous, 1994; Wilcut *et al.*, 1994c). Imazethapyr plus vernolate PPI followed by imazethapyr applied at GC provided more consistent control of purple nutsedge in North Carolina than either herbicide alone (A.C. York, unpubl. data, 1993). Greenhouse research found that imazethapyr is most effective on purple nutsedge when applied PPI (Richburg *et al.*, 1993). Control from early POST or POST applications were less effective.

Imazethapyr also can be applied POST for yellow nutsedge control (Wilcut, 1991c; Grichar *et al.*, 1992; Richburg *et al.*, 1993, 1995d). Yellow nutsedge control with imazethapyr is best with PPI treatment and least effective with POST treatments. However, if imazethapyr is used POST, it needs to be applied when yellow nutsedge is 5 to 10 cm tall for greatest efficacy (Wilcut 1991c; Richburg *et al.*, 1993; Wilcut *et al.*, 1994c). Bentazon applied POST controls yellow nutsedge better than imazethapyr (A.C. York and J.W. Wilcut, unpubl. data, 1994).

Foliar-Applied Graminicides. Two postemergence graminicides are registered in peanut, fenoxaprop and sethoxydim. Sethoxydim provides a broader spectrum of control and is more consistent than fenoxaprop. There are no advantages for use of fenoxaprop compared to sethoxydim (J.W. Wilcut and A.C. York, unpubl. data). Sethoxydim applied POST controls annual and perennial grasses but lacks residual control. Two applications of sethoxydim are often required for control of the perennial grasses, johnsongrass and bermudagrass (Grichar and Boswell, 1989; Wilcut, 1991b). Sethoxydim is most active if the grass weeds are not moisture stressed when treated. The sethoxydim registration label recommends the use of a crop oil concentrate for improved grass control compared to control from sethoxydim and a nonionic surfactant (Anonymous, 1994). BCH 81508 S, $(NH_4)_2SO_4$ and UAN can be added with crop oil for more consistent control (Anonymous, 1994).

Adding $(NH_4)_2SO_4$ did not increase sethoxydim control of johnsongrass or bermudagrass but did increase large crabgrass control (York *et al.*, 1990). Seedling and rhizome johnsongrass, large crabgrass, and common bermudagrass control were improved when BCH 81508 S was used with sethoxydim instead of crop oil concentrate (York *et al.*, 1990). The addition of BCH 81508 S increased the efficacy of lower rates of sethoxydim while providing little enhancement of control from higher rates of sethoxydim.

The perennial grasses such as bermudagrass and johnsongrass, are only controlled with POST-applied graminicides (Grichar and Boswell, 1986, 1989; Wilcut, 1991b). Sethoxydim is the only registered herbicide to provide adequate control of bermudagrass and two applications are frequently required (Grichar and Boswell, 1989; Wilcut, 1991b; Anonymous, 1994).

The POST graminicides, fenoxaprop and sethoxydim, generally provide less grass control when they are mixed with POST broadleaf-controlling herbicides, especially acifluorfen, bentazon, and imazethapyr (Grichar and

Boswell, 1987b; Grichar, 1991a,b). Acifluorfen, bentazon, acifluorfen plus bentazon and pyridate reduced Texas panicum and southern crabgrass control when mixed with sethoxydim (Grichar and Boswell, 1987b; Wilcut *et al.*, 1994c). Substituting BCH 81508 S for crop oil concentrate with mixtures of bentazon plus sethoxydim improved large crabgrass control (Jordan and York, 1989). 2,4-DB did not reduce control of Texas panicum, large crabgrass, and broadleaf signalgrass with sethoxydim but decreased rhizome johnsongrass control (York *et al.*, 1993).

Foliar-Applied Broadleaf Herbicides. Bentazon applied POST controls bristly starbur, coffee senna, common cocklebur, common lambsquarters, prickly sida, smallflower morningglory, spurred anoda, velvetleaf, and yellow nutsedge (Grichar, 1992; Wilcut *et al.*, 1994c). Small common ragweed can be controlled with bentazon and crop oil (A.C. York, unpubl. data, 1993). Bentazon commonly is mixed with acifluorfen or as a 2:1 prepackage mixture (Anonymous, 1994) of bentazon plus acifluorfen in the Virginia-North Carolina and southwestern region or mixed with paraquat in the southeastern peanut region. Bentazon does not control eclipta, Florida beggarweed, *Ipomoea* morningglory species, *Amaranthus* species, and sicklepod nor does it provide residual control (Wilcut *et al.*, 1994c).

Paraquat provides good to excellent control of Florida beggarweed and sicklepod (Wilcut *et al.*, 1989a; Wilcut, 1991c). These broadleaf weeds are the two most common and troublesome weeds for southeastern peanut production (Tables 4 and 5). Although paraquat applied POST to peanut injures the foliage (Wehtje *et al.*, 1986; Brecke and Colvin, 1988; Wilcut and Swann, 1990), peanut rapidly recovers under good growing conditions and yield is unaffected. Peanut tolerance to paraquat is not cultivar dependent (Knauft *et al.*, 1990) and seedling tolerance to paraquat is not influenced by seed size (Wehtje *et al.*, 1994). Paraquat can be applied from crop emergence until 28 DAE (Anonymous, 1994). Paraquat applied after this 28-day period increased the chance of significant yield reductions (Wehtje *et al.*, 1986; Brecke and Colvin, 1988).

Wehtje *et al.* (1991a,b,c, 1992a,b,c) conducted a series of studies that examined the compatibility of paraquat with other registered herbicides commonly applied POST in peanut. In greenhouse and field experiments, naptalam (Wehtje *et al.*, 1991a), chloramben (Wehtje *et al.*, 1992c), and bentazon (Wehtje *et al.*, 1992a) reduced control of paraquat-sensitive weed species by paraquat. When both herbicides were active on the same species—e.g., paraquat and chloramben on Florida beggarweed—control was not reduced (Wehjte *et al.*, 1992c).

Laboratory studies using ^{14}C-labelled herbicides indicated that antagonism with herbicide mixtures was due primarily to reductions in paraquat absorption. Naptalam left deposits on leaf surface of peanut and selected weed species, which appeared to reduce paraquat absorption (Wehtje *et al.*, 1991a). Alachlor and metolachlor (Wehtje *et al.*, 1991b), and 2,4-DB (Wethje *et al.*, 1992b) either had no effect or slightly increased paraquat activity. Paraquat mixtures are important for sicklepod and Florida beggarweed control in the Southeast. The only beneficial mixture with paraquat are those where the added herbicide either increased the spectrum of weed species controlled (i.e., bentazon) or improved control of large weeds (i.e., 2,4-DB for sicklepod). No other mixtures improved weed control or peanut yield over that obtained with paraquat applied alone.

Paraquat, paraquat plus 2,4-DB, paraquat plus bentazon, and paraquat plus bentazon plus 2,4-DB mixtures are currently the POST standards for broadleaf weed control in southeastern peanut production (Wilcut *et al.*, 1989a, 1994c; Brecke and Colvin, 1991). Paraquat plus bentazon plus 2,4-DB mixtures provide the broadest and most consistent spectrum of broadleaf weed control of any POST combination registered for use in southeastern peanut production (Wilcut *et al.*, 1992a, 1994c).

Paraquat plus bentazon mixtures control more broadleaf weed species than paraquat or bentazon alone, including bristly starbur, coffee senna, prickly sida, and smallflower morningglory (Wilcut *et al.*, 1994c). Bentazon also reduces paraquat-induced foliar injury to peanut by reducing paraquat absorption into peanut foliage (Wehtje *et al.*, 1992a). Although paraquat absorption also was reduced in several weed species—including Florida beggarweed, sicklepod, and Texas panicum (Wehtje *et al.*, 1992a)—control of these species was not reduced unless the application was made to weeds larger than the size recommended for application (greater than 5 cm tall).

Apparently very little herbicide absorption is needed for good control since weeds controlled by either herbicide are extremely sensitive to the respective herbicide. Control of species not highly sensitive to either herbicide, most notably sicklepod, will be reduced if applications are made to larger weeds than optimum (5 cm tall). The paraquat plus bentazon mixture quickly gained acceptance across the Southeast and became a standard component of many commercial weed management programs (Wilcut *et al.*, 1994c).

Paraquat and paraquat plus bentazon and/or 2,4-DB mixtures also are used by some producers in the Virginia-North Carolina region but not to the extent as in the rest of the southeastern U.S. Paraquat does not adequately control common lambsquarters, common ragweed, prickly sida, spurred anoda, and tropic croton (Wilcut and Swann, 1990; Wilcut, 1991a,c; Wilcut *et al.*, 1994c). These weeds are commonly found in Virginia and North Carolina and to a lesser extent in the rest of the southeastern U.S. (Tables 4 and 5).

Very little paraquat is used in the Southwest since many weeds are effectively controlled with PPI or PRE herbicides. Also, producers in the Southwestern area are slow to accept any herbicide which injures peanut (W.J. Grichar, pers. obs., 1994).

Peanut is tolerant of 2,4-DB applied POST for broadleaf weed control (Buchanan *et al.*, 1982). A single application of 2,4-DB at 0.9 kg ae/ha to peanut during the reproductive stage (the most herbicide-sensitive period) reduced both yield and market grade (Ketchersid *et al.*, 1978). However, repeated applications of 0.45 kg/ha had no effect. The normal use rate is 0.28 kg/ha. 2,4-DB is used for controlling broadleaf weeds including common cocklebur, *Ipomoea* morningglory species, sicklepod, and smallflower morningglory (Buchanan *et al.*, 1982). Smallflower morningglory is more tolerant of 2,4-DB than *Ipomoea* morningglory species (Wilcut *et al.*, 1994c). Pitted morningglory is the most 2,4-DB-tolerant *Ipomoea* morningglory species (Barker *et al.*, 1984). 2,4-DB applied POST following alachlor applied PRE provides near complete bristly starbur control (Wilcut *et al.*, 1992).

Many POST broadleaf herbicides are applied in mixture with 2,4-DB which helps improve control of many broadleaf species, particularly if the broadleaf weeds are larger than recommended size for treatment with herbicides such as acifluorfen, bentazon, paraquat, and pyridate (Wilcut *et al.*, 1994c). It is also commonly applied with foliar fungicides to reduce the expense of making two separate applications.

Acifluorfen applied POST is widely used in the Virginia-North Carolina and southwestern peanut regions of the U.S. Acifluorfen controls *Amaranthus* species, common lambsquarters, common ragweed, eclipta, horse purslane, jimsonweed, smartweed, and tropic croton (Buchanan *et al.*, 1982; Wilcut and Swann, 1990; Wilcut, 1991a,c; Grichar, 1993; Wilcut *et al.*, 1994c). Only small cocklebur are controlled with acifluorfen. Acifluorfen does not adequately control bristly starbur, coffee senna, Florida beggarweed, prickly sida, sicklepod, or spurred anoda (Wilcut *et al.*, 1994c). Acifluorfen at rates used POST in peanut does not provide residual control (Wilcut *et al.*, 1994c).

Acifluorfen plus bentazon is a standard mixture in the Virginia-North Carolina and southwestern regions (Wilcut *et al.*, 1991a,b). Acifluorfen plus bentazon mixtures control most broadleaf weed species, except Florida beggarweed and sicklepod. Rates of acifluorfen and bentazon in the mixture may need to be adjusted for certain troublesome weed species such as common lambsquarters, common ragweed, prickly sida, spurred anoda, and yellow nutsedge. The bentazon rate needs to be increased for consistent control of prickly sida, spurred anoda, and yellow nutsedge while the acifluorfen rate should be increased for common ragweed and common lambsquarters (Wilcut *et al.*, 1994c). However, acifluorfen plus bentazon is often applied as a commercially available prepackaged 2:1 ratio of bentazon to acifluorfen (Anonymous, 1994).

Imazethapyr applied POST provides the broadest spectrum and most consistent control when applied within 10 days of weed emergence (Wilcut *et al.*, 1991a, 1994a,b). Imazethapyr is the only POST herbicide to control both yellow and purple nutsedge (Grichar *et al.*, 1992; Richburg *et al.*, 1993). Control is most effective when imazethapyr is applied to the soil or yellow nutsedge that is no more than 5 to 10 cm tall (Richburg *et al.*, 1993; Wilcut *et al.*, 1994c). Other research has reported good nutsedge control with imazethapyr applied PPI plus GC.

Imazethapyr provides excellent full-season control (greater than 90%) of bristly starbur, coffee senna, *Ipomoea* morningglory species, prickly sida, smallflower morningglory, and spurred anoda (Wilcut, 1991c; Wilcut *et al.*, 1991a,b, 1994a,b,c). Coffee senna, prickly sida, and spurred anoda can be controlled if imazethapyr is applied when the weeds are in the two-leaf growth stage or smaller (Wilcut *et al.*, 1994c). Larger weeds become tolerant of it. Bristly starbur less than 4-cm tall is extremely sensitive to imazethapyr (Wilcut *et al.*, 1994c). However, bristly starbur taller than 4 cm is not controlled by imazethapyr. Imazethapyr will kill only the terminal growing point of taller bristly starbur (Wilcut *et al.*, 1994c).

Paraquat plus imazethapyr as an early POST application provided excellent control of broadleaf and nutsedge species in Georgia (Wilcut *et al.*, 1994a). There were no significant interactions for a paraquat plus imazethapyr mixture. Paraquat plus imazethapyr provided better full-season control of many weed species than paraquat plus bentazon due to the residual control from imazethapyr (Wilcut *et al.*, 1994a). Imazethapyr does not reduce paraquat injury to peanut like bentazon. Bentazon and imazethapyr frequently control the same species, including bristly starbur, coffee senna, prickly sida, smallflower morningglory, spurred anoda, and yellow nutsedge.

Chlorimuron applied late-POST provides effective late-season Florida beggarweed control (Colvin and Brecke, 1988b; Wehtje *et al.*, 1993). Chlorimuron can be applied from 60 DAE until 45 days prior to harvest (Anonymous, 1994), but early application increases the potential for significant yield reductions (Colvin and Brecke, 1988b). If weeds are actively growing with good soil moisture, chlorimuron also may control bristly starbur, morningglory species including smallflower, and sicklepod (Wilcut *et al.*, 1994c). However, late POST-applied chlorimuron generally controls only Florida beggarweed. Sicklepod can be controlled with chlorimuron but greatest control comes from chlorimuron applications to two- to three-leaf growth stage (Wilcut *et al.*, 1994c).

Decreased alachlor use and without other herbicides for early season suppression of Florida beggarweed, may result in reduced chlorimuron activity on Florida beggarweed. Chlorimuron consistently controls Florida beggarweed less than 25-cm tall (Colvin and Brecke, 1988b; Wehtje *et al.*, 1993; Wilcut *et al.*, 1994c). Without some early season suppression, Florida beggarweed often is larger than 25 cm when chlorimuron is applied, resulting in inconsistent control (Wilcut *et al.*, 1994c). Irrigated peanut should be watered 4 or 5 days before chlorimuron application to improve efficacy if the weeds are moisture stressed (Wilcut *et al.*, 1994c). Additionally, the potential for yield reduction from chlorimuron is increased if peanut is moisture stressed when chlorimuron is applied.

The interaction of 2,4-DB and chlorimuron on weed control and crop safety in peanut was examined (Wehtje *et al.*, 1993). Greenhouse trials found that mixtures of these herbicides were non-interactive. Studies with ^{14}C-labelled herbicides revealed that absorption and translocation of chlorimuron and 2,4-DB was not affected by presence of the other herbicide. In field studies, Florida beggarweed control with chlorimuron was not influenced by adding 2,4-DB. The primary benefit of mixing 2,4-DB with chlorimuron was for improved control of sicklepod and *Ipomoea* morningglory species (Wehtje *et al.*, 1993).

ECONOMICS OF WEED CONTROL IN PEANUTS

The economic assessment of weed management systems is essential information for producers to maximize profits. Unfortunately, weed control recommendations often are based upon the level of control achieved with an application rather than on economic effectiveness. Weed control systems providing the highest levels of weed control are often not the most economical. Economic returns from increased sicklepod control in soybean were less than returns from less intensive control systems (Bridges and Walker, 1987). Excessive herbicide application or too many cultivations have lowered peanut yields and net returns (Hauser *et al.*, 1974). Weed scientists and agricultural economists must work together to identify both efficacious and cost-effective management systems for producers.

Prior to cancellation of dinoseb registration, researchers in Alabama examined economics of various management systems utilizing herbicides and cultivations (Bridges *et al.*, 1984; Wilcut *et al.*, 1987b,c). Neither cultivation nor herbicides alone provided the highest levels of weed control, peanut yield, or net returns. A combination of a herbicide system with one or two timely cultivations provided the best weed control and greatest peanut yield and net returns.

The economics of alternatives to dinoseb were assessed in the late 1980's in Alabama (Wilcut *et al.*, 1989a). Substituting paraquat for dinoseb provided equivalent weed control and equivalent or higher peanut yields and net returns. Also, paraquat systems resulted in weed control, yield, and net returns equivalent to the alachlor plus paraquat systems. These findings were substantiated in later research (Wilcut *et al.*, 1990c, 1993a).

In Virginia, two POST paraquat applications were economically effective for common ragweed control in virginia-type peanut following a PPI application of vernolate and a dinitroaniline herbicide (Wilcut and Swann, 1990). Paraquat should be applied at GC for common ragweed control, high yields, and net returns. Delaying initial paraquat application until 2 weeks after ground cracking (WGC) in Virginia provided 35% less control of common ragweed, reduced peanut yields by about 1200 kg/ha, and resulted in a net loss of approximately $400/ha compared with a GC paraquat application.

Further research on economic yield response of peanut to POST herbicides in Virginia illustrated the economic effectiveness of early application (Wilcut, 1991a). Acifluorfen plus bentazon provided equivalent net returns when applied at GC or 2 WGC, but net returns from an application 4 WGC were $760/ha less. Paraquat plus bentazon provided net returns of $1116/ha when applied at GC compared with $471/ha when applied 2 WGC. Net returns were greatest with paraquat applied at GC ($720/ha) compared with 2 WGC ($84/ha). Economic returns of $645/ha for tropic croton control were greatest with acifluorfen plus bentazon plus 2,4-DB were applied at 2 WGC, while paraquat applied at the same time returned $47/ha (Wilcut, 1991c).

In Virginia, common bermudagrass control required sequential POST graminicide applications (Wilcut, 1991b). However, peanut yields and net returns generally were not increased with sequential graminicide applications compared with a single application.

POTENTIAL NEW HERBICIDE REGISTRATIONS

Numerous herbicides have been evaluated in peanut since 1982. Herbicides that have potential for weed control and registration in peanut include lactofen, AC 263,222, and clethodim.

Lactofen, a diphenylether herbicide, is currently registered for use in soybean. Peanut has tolerance of PRE, GC, or POST applications of lactofen (Moore *et al.*, 1990; Wilcut *et al.*, 1990a; Jordan *et al.*, 1993). Depending on application method, lactofen controls common lambsquarters, common ragweed, eclipta, Florida beggarweed, *Ipomoea* morningglory species, prickly sida, smallflower morningglory, spurred anoda, tropic croton, and wild poinsettia (Moore *et al.*, 1990; Wilcut *et al.*, 1990a). Lactofen is not as efficacious as acifluorfen on *Ipomoea* morningglory species (Higgins *et al.*, 1988) but provides better control of common ragweed, prickly sida, and spurred anoda (Wilcut *et al.*, 1990a).

AC 263,222 is an imidazolinone herbicide which has shown outstanding activity on a number of weed species (Nester and Grichar, 1993; Wilcut *et al.*, 1993b, 1994b, 1995; Richburg *et al.*, 1994, 1995a,d). AC 263,222 is similar to imazethapyr and controls all the weeds controlled by imazethapyr. In addition, AC 263,222 controls two extremely common and troublesome weeds, Florida beggarweed and sicklepod, which are not adequately controlled by imazethapyr. Whereas imazethapyr provides consistent control of many broadleaf and sedge species if applied within 10 DAE, AC 263,222 has a longer time period for effectiveness of POST application (Wilcut *et al.*, 1993b, 1995; Richburg *et al.*, 1994, 1995a,d). AC 263,222 also is effective for control of rhizome and seedling johnsongrass, Texas panicum, large and southern crabgrass, and broadleaf signalgrass (Wilcut *et al.*, 1993b). Peanut tolerance appears to be excellent with only minor differences in cultivar tolerances (Richburg *et al.*, 1995b). Carryover to cotton grown in rotation is a concern (York and Wilcut, 1995).

Clethodim is POST-applied graminicide being developed for peanut. It controls annual and perennial grass species and is similar to sethoxydim and fenoxaprop in control spectrum (Grichar and Boswell, 1986, 1987b; York *et al.*, 1993). Clethodim provides better bermudagrass control than either sethoxydim or fenoxaprop and controls *Digitaria* species better than fenoxaprop (Grichar and Boswell, 1989; Wilcut, 1991b; Anonymous, 1994; Wilcut *et al.*, 1994c).

ENVIRONMENTAL ASPECTS OF HERBICIDES REGISTERED IN PEANUT

Extensive information is now required on the safety of new pesticides for registration in the U.S. Herbicides registered earlier under less rigorous procedures are now required to undergo reregistration to ensure adequate safety. The research for registration and reregistration is the major cost in herbicide development. Herbicide development costs from $20 to $50 million or more and requires 6 to 10 years. In 1954, it was estimated that 1/1000 compounds evaluated would make it through registration. In 1984, only 1/18,000 was registered and, by the mid-1990s, the number is expected to decrease to 1/80,000. The escalating costs of registration and with the rapidly changing requirements due to newer more elaborate and expensive technology has resulted in registration of fewer new herbicides, particularly for small acreage crops like peanut.

The environmental fate of herbicides, particularly in relation to potential residues in food, are of increasing concern to the American public and regulatory agencies. Several herbicides registered in peanut have been listed by the EPA as potential groundwater contaminants (Aller *et al.*, 1985), including acifluorfen, alachlor, bentazon, metolachlor, and trifluralin. However, considerable data demonstrate that normal agricultural use of trifluralin poses no threat to groundwater based on soil sorption studies and a multitude of other research (Grover, 1988; Humburg, 1989; Grover and Cessna, 1991; Weber, 1991). The only threat trifluralin would pose to groundwater would be from point source contamination. The behavior of herbicides in soil, plant, and aquatic environments is a very complex area that is more fully discussed in other reviews (Hance, 1987; Grover, 1988; Cheng, 1990; Grover and Cessna, 1991; Mangles, 1991a,b; Weber, 1990). Hance (1987) also discussed problems with artificial systems that are utilized in the laboratory compared to findings in the field.

Weed management in the past 10 years has seen a 70% reduction in amount of herbicide active ingredient used for peanut production (Buchanan *et al.*, 1982; Wilcut *et al.*, 1994c). Older herbicides that required high use rates are being replaced with newer registrations that use less than 10% and often less than 1% of the active ingredient of the older registrations. For example, imazethapyr at 71 g/ha provides better perennial sedge control and controls many more troublesome broadleaf weed species than alachlor or metolachlor which were frequently used at rates exceeding 3.4 kg/ha. Paraquat at 140 g/ha replaced alachlor plus dinoseb plus naptalam mixtures which were applied at greater than 8.0 kg/ha.

SUMMARY AND FUTURE OPPORTUNITIES

The National Academy of Sciences released a summary of "Pesticides in the Diets of Infants and Children" in 1993. This report could have a dramatic effect on the peanut industry with peanut being a common component of children's diet. Food safety is of primary concern to all involved including the scientific and academic community, the general public, regulatory agencies, environmental activists, and pesticide and related agricultural industries.

Food safety, residue analyses, interpretation, management, and communication of risk is a complex area that goes far beyond this review

(Francis, 1992). It appears that a large part of the problem is due to a multitude of complex issues including vastly improved and rapidly improving analytical technology, how to interpret these new data, and a public that desires a "No Risk" food supply. Several informative publications are available for the reader to review some important facts in this area (Francis, 1992).

The future of the peanut industry and weed management in peanut may be influenced by the study mentioned above. In addition, the industry will be strongly impacted by the General Agreement on Tariffs and Trade (GATT). Without the current price support system, peanut production systems including weed management may have to be directed away from expensive, high-input systems designed for maximum quality production for least-cost and variable quality production systems. If the value of the peanut crop declines, this will also slow the development of new pesticides and technology for a minor crop like peanut (Camp, 1991). The increased cost of pesticide registration and reregistration, together with a drop in crop value could greatly diminish the development of new technology for peanut.

Despite the aforementioned concerns, there are many problems and opportunities for weed science in peanut. The increase of herbicide resistant weeds throughout the world and in North America is an area of increasing concern (Gressel and Segel, 1990; Holt and LeBaron, 1990; Powles and Howat, 1991; Powles and Werk-Reichart, 1992). New research indicates that resistant weeds are not necessarily less competitive (Holt and LeBaron, 1990) and that rotating herbicides or using herbicide mixtures based upon different target sites may not prevent or delay resistance (Gressel and Segel, 1990). In addition, resistant weeds have developed with cross resistance and multiple resistance to herbicides with dissimilar modes of action and enzyme target sites (Powles and Howat, 1991; Powles and Werk-Reichart, 1992).

New strategies for preventing or delaying development of resistance needs to be initiated in the near future (Gressel and Segel, 1990; Holt and LeBaron, 1990; Powles and Howat, 1991; Powles and Werk-Reichart, 1992). Cooperation will be needed between research and extension, academia and industry to develop new management programs that include an integrated system for control. Herbicide families with the same enzyme target site may need to have rotational restrictions on the frequency of use. All weed management methods, nonchemical, integrated approaches, biological agents, and herbicide-only programs, select for resistance development (Gressel and Segel, 1990).

New systems are being developed to integrate computers into the management decision-making process to minimize the impact on the environment while maintaining crop productivity, quality, and profitability. As discussed earlier, computer programs are being developed for integration of economic thresholds and herbicide effectiveness (Barbour and Bridges, 1992). Further efforts are underway at North Carolina State University to integrate herbicide selection in peanut based on efficacy with prediction of potential for herbicide leaching on various soil types (Weber, 1991). The development of computer programs that utilize environmental impact data, weed control efficacy, economic thresholds, and weed population dynamics could help improve peanut quality and profitability while reducing the impact to the environment.

More research is needed to fully understand the biology and population dynamics of weeds in peanut production. This type of research could improve understanding of the success or failure of various plant species to become "weeds" in peanut production. As a result, perhaps a cure for weed management in peanut could be developed instead of the annual remedial approach that man has utilized since the beginning of intensive agriculture (Zimdahl, 1991). While herbicides remain the key component of weed management systems, more integrated approaches are being utilized and developed including integrated computer models to aid management decision making processes, better POST herbicides that allow for more successful prescription management, and better management by the producer. The newer herbicides are active at much lower use rates and have greatly reduced toxicological profiles compared to older compounds like dinoseb.

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