Chapter 8

WEEDS AND THEIR CONTROL IN PEANUTS

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The weed flora associated with peanuts throughout the United States is characterized by high populations of many diverse plant species. Among these species are annuals and perennials, grasses and broadleaf, tall and prostrate, and highly competitive as well as those not so competitive. Preventing such weeds from seriously interfering with growth, development, and harvesting is a major concern in the production of peanuts.

Currently used tillage practices common to peanut production favor germination, growth, and development of weeds. Because weeds respond to the same environmental factors as peanuts, i.e., water, nutrients, light, and space, those portions of these factors used by the weeds are unavailable to the crop. Under some conditions, peanuts and weeds can coexist redundant for at least a part of the growing season without appreciably affecting the crop. However, at some point during the life cycle of the crop, as various factors become limiting, the presence of weeds may reduce yield or quality of peanuts and cause harvesting difficulty.

Successful production of peanuts demands that maximum economic yields be harvested from each field. To accomplish this goal, the competitive effects of weeds must be largely eliminated. Consequently, knowledge about weeds and how to control them are vital concerns in peanut production.

WEEDS AND THEIR BIOLOGY

General Principles of Plant Competition

An understanding of some general principles involved in competition among plants provides an increased perspective of competition between weeds and peanuts. The first principle involves the competitive effects that a plant exerts upon another. These effects depend upon the relative ability of the 2 plants to utilize growth factors from the environment. Similarities in foliar characteristics, root patterns, and methods of reproduction all contribute to the competitive relationships between weeds and crops. The more similar plants are, whether between or within species, the more they will compete with each other. Generally, those species that can better utilize the growth factors of the environment will dominate if population levels are similar. Tolerance to various stresses such as drought, temperature extremes, flooding or suboptimal soil pH and fertility levels may become important under some conditions.

A second principle of plant competition is that the first species occupying a given space has an advantage over species which invade later. Thus, growers should strive to plant on a clean seedbed. In tall-growing, shading crops such

as soybeans or cotton, weeds that emerge late in the season are frequently unable to effectively compete with the crop species. Knake and Slife (1965) have shown that giant foxtail (*Setaria faberi* Herrm.) seeded 3 weeks after corn was planted produced 567 kilos of dry matter per hectare whereas giant foxtail seeded 3 weeks after soybeans made practically no growth. Thus, soybeans compete better with giant foxtail than does corn. Weeds emerging late in the growing season usually compete with crops less than those emerging early in the season (Dawson, 1964, 1965; Brimhall et al., 1965; Burnside and Wicks, 1967; Hill and Santelmann, 1969). The reduced competition by later emerging weeds is directly influenced by the competitive ability of the crop species at the time the weeds emerge.

A third principle of plant competition is that weed species vary in competitive effects on a given crop. Staniforth (1965) reported that giant foxtail reduced soybean yields more than did either green foxtail [*Setaria viridis* (L.) Beauv.] or yellow foxtail [*Setaria lutenscens* (Weigel) Hubb.]. Velvetleaf (*Abutilon theophrasti* Medic.) competed more effectively with soybeans than did either yellow foxtail or green foxtail.

Soybean yields, according to Wilson and Cole (1966), were equally affected by tall morning glory [*Ipomoea purpurea* (L.) Roth.], ivyleaf morning glory [*Ipomoea hederacea* (L). Jacq.] or mixtures of both species when the total weed density was equal. As the density of morning glory increased, soybean yields decreased. Soybean yields and other plant characteristics were not seriously affected when morning glory was removed 6 to 8 weeks after soybeans were planted.

In sugarbeets Brimhall et al. (1965) reported that green foxtail was less competitive per plant than was redroot pigweed (*Amaranthus retroflexus* L.). When the density of foxtail was less than 1 plant per beet plant, yields were not reduced. When pigweed or pigweed plus green foxtail were grown with beets, yields were significantly reduced at densities as low as 1 weed per 8 beets. Zimdahl and Fertig (1967) later reported that, generally, broadleaf weeds were more competitive than annual grasses in sugarbeets.

Weed Competition in Peanuts

Peanut plants are less adapted to mechanical cultivation than are most other agronomic crops. Although initial elongation of the radicle is rapid, peanut foliage grows slowly. In the USA, peanuts are usually planted from April to June but complete ground cover (in conventional row spacings) is not attained until 8 to 10 weeks after planting. The peanut canopy is usually thinner in depth than crop canopies such as soybeans or cotton. Consequently, weeds, usually broadleaf species that germinate early and are not controlled by various weed control practices, "escape" the peanut canopy and compete with the crop relatively late in the growing season. Although these are often referred to as "late-season" weeds, research by Hauser et al. (1975) suggests that with at least 2 species, sicklepod and Florida beggarweed (see Table 1 for Latin names of common weeds in peanuts), germination is relatively early in the growing season but unless control is perfect these weeds may grow undetected within the peanut foliage until the weeds overtop the peanuts about midseason.

Because of the low-growing nature of peanuts, covering weeds with soil dur-

Table 1. Common and Latin names of weeds occurring in peanuts.

Common Name[a]	Latin Name
barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.
beggarweed, Florida	*Desmodium tortuosum* (Sw.) DC.
carpetweed	*Mollugo verticillata* L.
cocklebur, common	*Xanthium pensylvanicum* Wallr.
copperleaf	*Acalypha* spp.
crabgrass	*Digitaria* spp.
croton	*Croton* spp.
crowfootgrass	*Dactyloctenium aegyptium* (L.) Richter
foxtail	*Setaria* spp.
goosegrass	*Eleusine indica* (L.) Gaertn.
hairy indigo	*Indigofera hirsuta*
honeyvine milkweed	*Baptisia indigo*
horsenettle	*Solanum carolinense* L.
jimsonweed	*Datura stramonium* L.
johnsongrass	*Sorghum halepense* (L.) Pers.
lambsquarters, common	*Chenopodium album* L.
morning glory, smallflower	*Jacquemontia tamnifolia* (L.) Griseb.
morning glory, tall	*Ipomoea purpurea* (L.) Roth
nightshade, silverleaf	*Solanum elaeaginifolium* Cav.
nutsedge, purple	*Cyperus rotundus* L.
nutsedge, yellow	*Cyperus esculentus* L.
panicum, fall	*Panicum dichotomiflorum* Mich.
panicum, Texas	*Panicum texanum* Buckl.
pigweed	*Amaranthus* spp.
purslane, common	*Portulaca oleracea* L.
pusley, Florida	*Richardia scabra* L.
ragweed	*Ambrosia* spp.
sandbur	*Cenchrus* spp.
sedges	*Cyperus* spp.
sicklepod	*Cassia obtusifolia* L.
sida	*Sida* spp.
signalgrass, broadleaf	*Brachiaria platyphylla* (Griseb.) Nash.
smartweed, Pennsylvania	*Polygonum pensylvanicum* L.
starbur, bristly	*Acanthospermum hispidum* DC.

[a]Common names of weeds are those published by the Weed Science Society of America (WSSA) Subcommittee on Standardization of Common and Botanical Names of Weeds. Weed Science 19:435-476. 1971.

ing cultivation is not practical. In fact, the peanuts may suffer more than the weeds. Numerous workers (Boyle and Hammons, 1956; Anon., 1959; Garren, 1959, 1961; Boyle, 1967) have reported yield reductions following cultivation in which soil was allowed to partially cover peanut plants.

Because of the growth habits of the peanut plant, weed removal is extremely difficult once weeds become established in the row. After both peanuts and annual grass weeds, such as crabgrass and goosegrass, achieve some measure of growth, mechanical removal with tractor-mounted cultivators is impossible.

Plate 1. goosegrass (*Eleusine indica* (L.) Gaertn.)

Plate 2. smallflower morning glory (*Jacquemontia tamnifolia* (L.) Griseb.)

Plate 3. tall morning glory (*Ipomoea purpurea* (L.) Roth)

Plate 4. ivy leaf morning glory (*Ipomoea hederacea*) (L.) Jacq.)

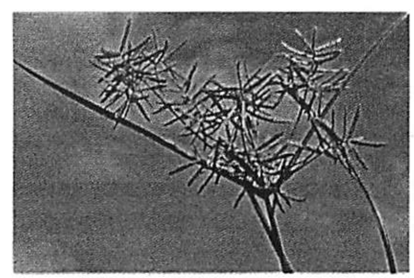

Plate 5. yellow nutsedge (*Cyperus esculentus* L.)

Plate 6. Texas panicum (*Panicum texanum* Buckl.)

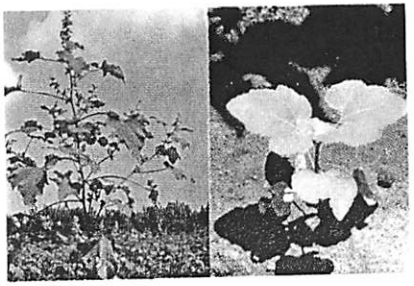

Plate 7. common cocklebur (*Xanthium pensylvanicum* Wallr.)

Plate 8. croton (*Croton* spp.)

Plate 9. Florida pusley (*Richardia scabra* L.)

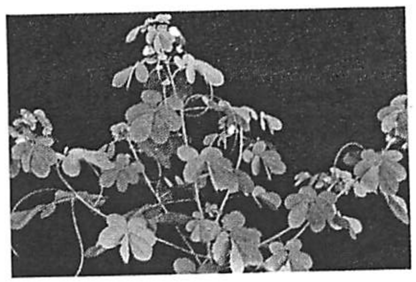

Plate 10. sicklepod (*Cassia obtusifolia* L.)

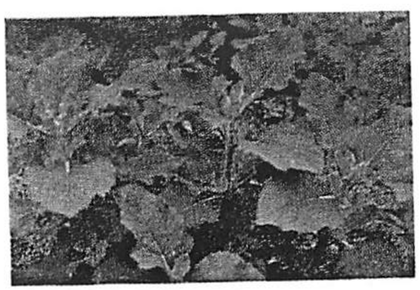

Plate 11. bristly starbur (*Acanthospermum hispidum* DC.)

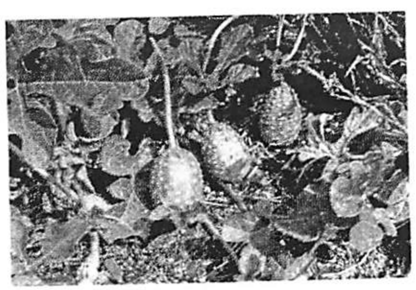

Plate 12. bur gherkin (*Cucumis anguria* L.)

Plate 13. Florida beggarweed (*Desmodium tortuosum* (Sw.) DC.)

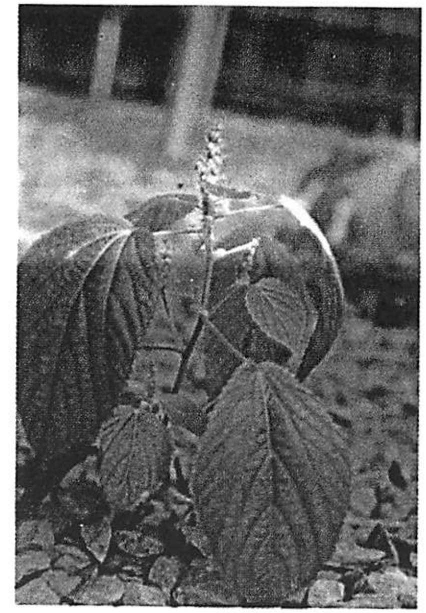

Plate 14. copperleaf (*Acalypha* spp.)

Plate 15. crowfootgrass (*Diactyloctenium aegyptium* (L.) Richter)

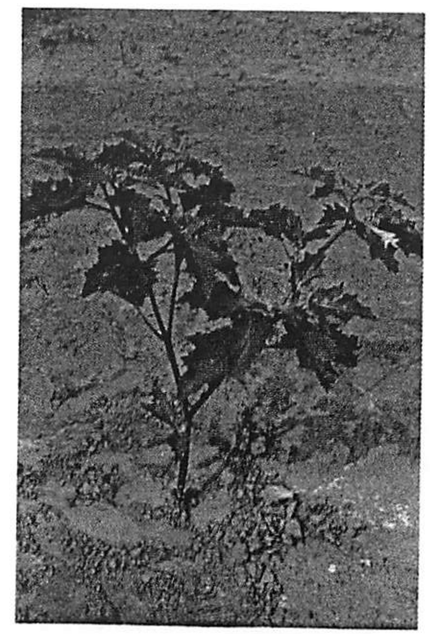

Plate 16. jimsonweed (*Datura stramonium* L.)

Plate 17. common lambsquarters (*Chenopodium album* L.)

Plate 18. fall panicum (*Panicum dichotomiflorum* Mich.)

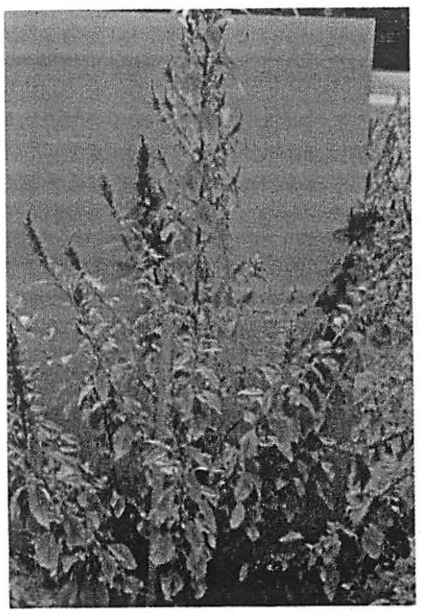

Plate 19. pigweed (*Amaranthus* spp.)

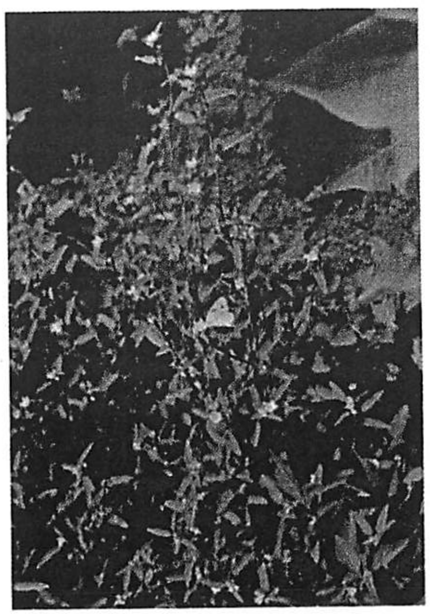

Plate 20. sida (*Sida* spp.)

Hand weeding is difficult, costly, and unrealistic under modern-day conditions. Consequently, peanut growers very rapidly accept chemical weed control practices.

Oram (1961) reported that when peanuts were grown under irrigation (which promoted rapid and vigorous growth of weeds) on the sandy soils of Libya, unweeded plots yielded less than half as much as weeded plots. He found that higher peanut yields depend on weed suppression late in the growing season, since careful hand weeding following herbicide treatments improved weed control and resulted in substantial yield increases.

Hauser and Parham (1969) reported from an 8-year study that natural infestations of annual weeds reduced the average yield of harvestable peanuts about 20%. Yield reductions ranged from 1 to 50%, depending primarily upon weed density. The predominant weeds were large crabgrass and Florida pusley. The authors suggested that competitive pressures and resultant yield reductions might have been different had other weed species been present. In later research, Buchanan et al. (1976) showed that sicklepod (growing with peanuts all season) reduced the yield of peanuts by 61%. In herbicide-crop rotation research (Hauser et al., 1974), yellow nutsedge and annual weeds reduced the yield of peanuts by 80%. York and Coble (1977) found that fall panicum reduced the yield of peanuts by as much as 90%.

Influence of Time and Duration of Weed Competition on Peanuts. In Oklahoma, Hill and Santelmann (1969) studied peanut growth and yields as affected by weed growth of different durations and at various stages of crop growth. Peanut yields were not reduced when weeds (principally crabgrass and smooth pigweed) were removed within 3 weeks after planting and the peanuts were kept weed-free for the remainder of the season. Yields were reduced when weeds were allowed to compete for 4 to 8 weeks after peanuts were planted. When peanuts were kept weed-free for at least 6 weeks after planting, no yield reductions due to weed competition occurred from weeds which germinated after this critical period. As weed competition increased, yield of peanuts, yield of forage, and soil moisture decreased. In North Carolina, York and Coble (1977) found that peanut yields were reduced by 2 or more weeks of competition with fall panicum. However, Hauser et al. (1975) found that with Florida beggarweed and sicklepod, at least 10 weeks competition was needed for these weeds to reduce the yield of peanuts. If peanuts were maintained free of these weeds for 4 to 6 weeks, the yield of peanuts was not reduced. In a companion study Buchanan et al. (1976) found that peanut foliage, released from weed-free maintenance after 8 weeks, suppressed 95% of the sicklepod for the remainder of the season, thus illustrating the competitive capacity of the peanut plant.

Competitive Ability of Particular Weed Species in Peanuts. The competitive ability of specific weed species in peanuts has received little study. Rawson (1963, 1964) reported that an infestation of morning glory may reduce yields of peanuts by about 7.5%. Noogoora bur (*Xanthium pungens* Wallr.), a plant similar to common cocklebur, when present at a density of 1 plant per 0.83 sq. meter reduced peanut yields approximately 16%. It is likely that common cocklebur would reduce the yield of peanuts to a similar degree. In Alabama, 3 or more sicklepod or Florida beggarweed plants per 0.9 linear m of row reduced yield of peanuts by approximately 50%. In later studies, only 1 sicklepod plant per 0.91 meter of row resulted in 30% loss of peanut yield. In these studies, higher weed populations also resulted in a higher incidence of leaf spot even though considerable effort was made to effect control (Buchanan, unpubl. data). In North Carolina, yield of peanuts was reduced 25% by 1 fall panicum plant every 4.8 meters of row. A density of 1 fall panicum plant per 0.3 meters of row reduced yields by 69% (York and Coble, 1977).

Influence of Weeds on Harvesting Peanuts. All aspects of peanut production are now mechanized and most cultural operations are handled with multiple-row equipment. Although weeds seriously reduce the yield of peanuts through competition, major losses also occur by weeds interfering with efficient harvesting.

During digging, the peanut plant is lifted out of the ground and, with an "inverter" device, the peanuts are exposed directly to the sun. A heavy stand of weeds, especially grasses and viny weeds, makes this operation almost impossible. The tight fibrous root system of the weeds becomes entwined with the peanut plant, and when this occurs many peanuts are stripped from the vine during digging operations. Peanuts that become detached from the plant remain unharvested in or on the soil.

If broadleaf weeds and annual grasses are present in high populations, substantial quantities of soil are brought up with the peanuts. This soil and weed foliage slows the drying process. Clearly, weeds increase harvesting difficulty, cause loss of peanut pods, and often remain as foreign matter in the harvested peanuts.

Major Weeds in Peanuts

The major weeds occurring in peanuts are those commonly associated with row crops in the southern and southwestern United States (see Tables 2 and 3). Annual grasses such as large crabgrass, goosegrass, Texas panicum and broadleaf signalgrass are currently the most troublesome grass species. The crabgrasses, goosegrasses, and Texas panicum are also among the most common weeds occurring in peanut fields. Texas panicum is now a major problem throughout southwestern Georgia, southeastern Alabama and in some areas of Oklahoma and Texas (Chandler and Santelmann, 1969 a,b). Texas panicum produces large seeds and is a vigorous, fast-growing grass. According to Chandler and Santelmann, maximum germination occurred at a depth of 1.3 to 3.8 cm. Seedling emergence declined with each increase in depth down to 8 cm. although some plants emerged from this depth. Other grasses that are found in peanut fields but which are of less general importance include fall panicum, johnsongrass, and sandbur.

Morning glory, common cocklebur, pigweeds, sicklepod, Florida beggarweed, Florida pusley, and bristly starbur are among the most common (broadleaf) weeds occurring in peanuts. These species, along with prickly sida, are the most troublesome weeds that infest peanut fields. Numerous other broadleaf species including carpetweed, purslane, Pennsylvania smartweed, common ragweed, lambsquarters, horsenettle, silverleaf nightshade, copperleaf, croton, and jimsonweed also occur in peanuts.

Table 2. Most common weed species in peanuts as reported by research scientists and extension personnel rank of importance.

State and reporter	1	2	3	4	5	6	7	8	9	10
Alabama D. Harzog	Florida beggarweed	Texas panicum	sicklepod	bristly starbur	nutsedges	common cocklebur	crabgrasses	goosegrass	morning glories	Florida pusley
Florida D.H. Teem W.L. Currey	crabgrasses	Florida pusley	Florida beggarweed	sicklepod	Texas panicum	bristly starbur	nutsedges	morning glories	common cocklebur	goosegrass
Georgia J.F. Miller C. W. Swann	crabgrasses	Florida pusley	nutsedges	sicklepod	Florida beggarweed	common cocklebur	morning glories	Texas panicum	pigweed	crotons
N.C. H. D. Coble L. F. Thompson, Jr.	crabgrasses	redroot pigweed	common ragweed	fall panicum	common cocklebur	goosegrass	nutsedges	morning glories	lambs-quarter	sicklepod
Oklahoma D. S. Murray H. A. L. Greer	crabgrasses	pigweed	Texas panicum	johnson-grass	prickly sida	copperleaf	morning glories	nutsedges	horsenettle	signalgrass
S.C. B. J. Gosset	crabgrasses	pigweed	goosegrass	sicklepod	Florida beggarweed	nutsedges	morning glories	common cocklebur	common ragweed	Florida pusley
Texas M. G. Merkle	crabgrasses	pigweed	Texas panicum	purslanes	carpetweed	nutsedges	signalgrass	crotons	morning glories	silverleaf nightshade
Virginia R. E. Rud	crabgrasses	goosegrass	nutsedges	morning glories	pigweed	fall panicum	lambsquarter	common cocklebur	jimson weed	

Table 3. Most troublesome weeds in peanuts as reported by research and extension personnel rank of importance.

State and Reporter	1	2	3	4	5	6	7	8	9	10
Alabama D. Hartzog	Florida beggarweed	sicklepod	bristly starbur	Texas panicum	common cocklebur	nutsedge	morning glories	sandbur	Florida pusley	crabgrass
Florida D. H. Teem W. L. Currey	Florida beggarweed	sicklepod	nutsedges	Texas panicum	bristly starbur	sandbur	Florida pusley	hairy indigo	goosegrass	morning glories
Georgia J. F. Miller C. W. Swann	Florida beggarweed	sicklepod	Texas panicum	common cocklebur	morning glories	crotons	nutsedges	crabgrasses	sandbur	bristly starbur
N. C. L. F. Thompson, Jr., H. D. Coble	sicklepod	broadleaf signalgrass	fall panicum	common ragweed	goosegrass	morning glories	common cocklebur	nutsedge	horsenettle	prickly sida
Oklahoma D. S. Murray, H.A.L. Greer	horsenettle	copperleaf	nutsedges	johnson-grass	silverleaf nightshade	crotons	pigweeds	morning glories	prickly sida	honeyvine milkweed
S. C. B. J. Gossett	sicklepod	Florida beggarweed	nutsedges	morning glories	common ragweed	pigweeds	goosegrass	prickly sida	crabgrasses	common cocklebur
Texas M.G. Merkle	nutsedges	Texas panicum	morning glories	broadleaf signalgrass	crotons	silverleaf nightshade	horsenettle	pigweeds	prickly sida	copperleaf
Virginia R. E. Rud	nutsedges	morning glories	crabgrasses	fall panicum	common cocklebur	goosegrass	pigweeds	lambs-quarter	jimson weed	

Yellow nutsedge, purple nutsedge, as well as several species of annual sedges, are among the most ubiquitous weeds in peanuts. They are extremely difficult, if not impossible, to control mechanically. Many herbicides currently used in peanut fields, such as substituted anilines, have no measurable activity against the nutsedges. Extensive use of these herbicides in some areas appears to contribute to increases in sedge populations, particularly in the southeastern states. Fortunately, herbicides of the thiocarbamate and amide groups offer some control of the sedges in peanuts as well as in other crops normally grown in rotation with peanuts.

A summary of the most common and most troublesome weeds in peanuts, as reported by research and extension personnel from 8 states, is presented in Table 4. Although considerable variation occurred in ranking the various weed species by different reporters, there was striking agreement as to the total weed list.

Interrelationships of Peanut Diseases and Weed Control

Increased knowledge of the interrelationships between weed control and certain diseases of the peanut plant tremendously influenced both the philosophy and practices of controlling weeds. Over 50 years ago, Silayan (1917) reported that in the Philippines flat cultivation resulted in higher yields of peanuts than did ridge cultivation. The importance of this provincially published research apparently remained unrecognized for about 30 years. Venezuelan investigators Ciccarone and Platone (1949) first correlated ridge cultivation with infestations of *Sclerotium rolfsii* Sacc., the causative organism of peanut stem rot. Piling soil into the row created conditions favorable for growth of this fungus.

The research of Boyle (1952, 1956) first clarified the interrelationships between methods of weed control in peanuts and the incidence of both stem rot and *Rhizoctonia* spp. He pioneered the principles for controlling stem rot through appropriate land preparation and subsequent weed control procedures. Boyle (1952) reported that flat culture involving application of a herbicide helped control stem rot. Later, Boyle and Hammons (1956) increased the yield of peanuts (up to 32%) with new methods of culture, including (a) turning all litter at least 8 cm. deep, (b) planting in flat beds followed by application of a herbicide as a preemergence treatment and (c) cultivating only where necessary without moving soil to, or ridging it against, the row of plants. They indicated that planting conventionally in a furrow, then subsequently cultivating soil into the row, was hazardous because (a) the lower nodes on the peanut plant were covered with soil thus smothering potential branches, flowers, fruits; and (b) the stage for severe disease outbreaks was set.

The intensive studies of Garren (1959, 1961) supported Boyle's research. Garren achieved what he labeled "non-dirting" weed control by (a) planting on slightly raised beds, (b) applying a herbicide as a preemergence treatment in bands over the row, and (c) cultivating the unsprayed middles without moving soil to the peanut row. Deeply covering the litter (which buries the weed seed on the soil surface) followed by "non-dirting" cultivation proved most beneficial. Garren considered "non-dirting" cultivation to be especially important. Further observations from North Carolina (Perry, 1955) correlated severe out-

Table 4. Most common and most troublesome weeds in peanuts and the number of states indicating inclusion on the appropriate list.

Most Common		Most Troublesome	
Weed	Number of reporters indicating that the species were among the 10 most common weeds in peanuts	Weed	Number of reporters indicating that the species were among the 10 most trouble some weeds in peanuts
crabgrass	8	morning glories	8
morning glories	8	nutsedges	8
nutsedges	8	common cocklebur	6
common cocklebur	6	sicklepod	5
pigweeds	6	crabgrass	4
goosegrass	5	Florida beggarweed	4
sicklepod	5	goosegrass	4
Texas panicum	5	pigweeds	4
Florida beggarweed	4	prickly sida	4
Florida pusley	4	Texas panicum	4
bristly starbur	2	bristly starbur	3
common ragweed	2	crotons	3
crotons	2	horsenettle	3
fall panicum	2	sandbur	3
lambsquarter	2	broadleaf signalgrass	2
signal grass	2	common ragweed	2
carpetweed	1	copperleaf	2
copperleaf	1	fall panicum	2
horsenettle	1	Florida pusley	2
jimsonweed	1	silverleaf nightsedge	2
johnsongrass	1	hairy indigo	1
prickly sida	1	honeyvine milkweed	1
purslanes	1	jimsonweed	1
silverleaf nightshade	1	johnsongrass	1
		lambsquarters	1

breaks of *S. rolfsii* with covering peanut leaves and stems during cultivation.

To facilitate flat-culture weed control, Shepherd (1963) devised methods for shaping flat "table-top" beds immediately after turning the soil. For controlling weeds in the bed before planting he used staggered, overlapping sweeps running flat and shallow in order not to bring litter back to the soil surface.

Although certain "non-dirting" cultivation tools such as "beetknives" kill very small weeds in the inter-row spaces, no cultural implement consistently kills weeds in the peanut row without depositing soil on or around the peanut plant. Although rotary hoes are popular in some localities for early weeding of peanuts, their use is generally discouraged because any implement which brings soil and dying weeds into contact with peanut plants provides a favorable medium for the development of stem rot.

The difficulties inherent in proper mechanical cultivation of peanuts contributed to an intensified search for acceptable herbicides. New and effective weed control practices, especially those which met the specifications of the plant pathologists, contributed to higher peanut yields directly through control of weeds and indirectly through disease prevention. Use of herbicides in peanut production is so well accepted that farmers now emphasize intensive or multiple application of herbicides.

At the present stage of development of the art and science of weed control, one might ask "should peanuts always be treated with herbicides?" Philosophically, the answer is "no" if weeds can be controlled satisfactorily with "non-dirting" cultivation. But the difficulties involved are numerous (McGill and Samples, 1968).

Recent research by Hauser et al. (1973) strongly suggests that at least 1 timely layby cultivation may be essential on certain soil types. Therefore, a logical balance between herbicides and precision cultivation may consist of using as little of both as is necessary to keep weeds under control.

With the present emphasis on sequences of herbicides in peanuts, the value of minimum but timely "non-dirting" cultivation can easily be underestimated. Also, closely spaced rows can prove to be a valuable tool not only for suppressing weed growth but also for minimizing the need for both herbicides and cultivation (Buchanan and Hauser, 1980).

HERBICIDES AND WEED CONTROL

Herbicide Research and Development - Historical Perspective

Research by weed scientists designed to control weeds in peanuts using herbicides dates from about 1949. Much of the early research involved use of the phenoxy herbicides (2,4-di- chlorophenoxy) acetic acid (2,4-D), (2,4,5-trichlorophenoxy) acetic acid (2,4,5-T), (2-(2,4-dichlorophenoxy)ethyl) phosphite (2,4-DEP), and sesone (Scholl and Searcy, 1949; Searcy, 1952, 1953; Helms and Rodgers, 1953; Westmoreland and Klingman, 1953; Rawson, 1962, 1963). While these herbicides controlled a number of weed species, they sometimes caused considerable injury to peanuts. Pentachlorophenol (PCP) was also evaluated extensively for control of weeds (Shaw et al., 1951; Helms and Rodgers, 1953; Upchurch and Selman, 1963). Early research indicated that dinoseb also controlled many weed species with less injury than occurred with the phenoxys (Shaw et al., 1951; Helms and Rodgers, 1953; Upchurch and Selman, 1963).

Witherspoon and Rogers (1954) controlled weeds for 8 to 15 weeks with dinoseb applied as an early postemergence spray. The next year, Rea (1955) found sesone safe if applied at layby but preemergence applications injured peanuts. Sesone reduced yields in Florida (Helms, 1955) and later Burt (1955) reported that both sesone and isopropyl m-chlorocarbanilate (chlorpropham) were ineffective but dinoseb performed well. Later Burt (1956) found that preemergence application of dinoseb injured peanuts more and controlled weeds less effectively than sesone when 7.6 cm. of rain fell immediately after treatment. Sesone controlled weeds better than the other herbicides evaluated as preemergence treatments in Georgia from 1953 to 1955 (Thompson et al., 1955). These results were confirmed by Wheatley and Wells (1955) in extensive farm demonstrations. Upchurch and Selman (1963) reported that sesone did not control weeds in North Carolina as effectively as in Georgia and that dinoseb controlled weeds less satisfactorily in North Carolina than in Florida.

Of 24 herbicides applied as preemergence treatments after planting or applied at the emergent stage of peanuts, only preemergence treatments with 3-(3,4-dichlorophenyl)-1,1-dimethylurea (diuron) and 2-(2,4,5-trichlorophenoxy) propionic acid (silvex) greatly reduced the stand and vigor of peanuts in Virginia (Chappell, 1956). In related research Chappell and Duke (1956) noted that peanut yields were not influenced by rate of sesone, planting depth, or rolling versus nonrolling of the soil surface. Chappell (1957) compared granular and spray formulations of several herbicides and pointed out the need for studies of herbicide mixtures. Later field experience showed that with proper application equipment, granular formulations controlled weeds effectively.

Watson and Nation (1957) found that although tolerance of peanuts to dinoseb applied as a postemergence spray varied, the herbicide could be effectively and safely used until the peanut plants were 8 cm. in diameter. However, unpublished data (Hauser et al.) showed that while dinoseb at 5.0 kg/ha did not affect peanut yields if applied "at cracking" under Georgia conditions, it did reduce both stands and yields if applied 7 days later. Hauser and Parham (1965) later reported that a low rate of dinoseb (1.7 kg/ha) applied as an overtreatment 7 or 14 days after peanuts emerged always increased crop injury and suggested that peanuts be shielded if dinoseb is applied after the "cracking" stage. In contrast, Rud and Chappell (1959) reported that dinoseb, at 3.4 to 10 kg/ha applied at growth stages up to 10 leaves, did not significantly reduce peanut yields.

Several conclusions can be made from the foregoing review of research conducted mostly from 1950-1960. First, extreme variation in weed control occurred with the same herbicides evaluated at different locations and under different environmental conditions (Thompson et al., 1955; Boswell et al., 1968). Both weed control and crop reaction to sesone and dinoseb, 2 of the herbicides evaluated most extensively as preemergence treatments in the 1950's, varied widely. Secondly, from these and later studies (Rud and Chappell, 1959; Hauser et al., 1962; Hauser and Parham, 1964; Boswell et al., 1968; Upchurch et al., 1968), dinoseb emerged as the most promising herbicide for use as a postemergence treatment for peanuts; but its activity varied as influenced by climatic conditions and the physiological condition of both peanuts and weeds. Thirdly, the peanut plant generally tolerated a number of herbicides.

Selectivity of many of these early candidate herbicides was based on: (a) limited physiological or biochemical tolerance, (b) differential herbicide concentration in the crop-seed zone versus the weed-seed zone and (c) protective morphological characteristics of the peanut plant. With limited biological selectivity existing between peanuts and certain weed species, differential concentration of herbicides in the crop-seed zone appeared functional with such compounds as 2,4-DEP, dinoseb and sesone. Under normal rainfall conditions, concentrations of these herbicides usually did not exceed that tolerated by the emerging peanut plant.

The peanut tolerates certain preemergence herbicide treatments such as 2,4-D, which severely injure many other legumes (Klingman, 1961). Apparently, certain morphological characteristics of the peanut plant provide partial protection against many herbicides. Unlike small-seeded legumes, peanut plants usually emerge vigorously within 5 to 7 days after planting. In addition, the primary taproot grows downward to depths of about 15 to 30 cm. below the seed by the time emergence occurs. Therefore, it can be assumed that, under normal conditions, most herbicides applied as preemergence treatments do not leach readily into the soil profile occupied by the rapidly growing taproot of the peanut plant.

Research from 1959-1969 emphasized mixtures of herbicides for peanuts in an effort to improve weed control while maintaining crop tolerance. Sesone or 2,4-DEP mixed with dinoseb and applied at the "cracking" stage produced excellent control of both crabgrass and Florida pusley in Georgia (Hauser and Parham, 1964). Components of the mixtures, sprayed alone at twice the rate used in the combination, did not control weeds as well or as long. Results from Florida were similar (Wilcox and Lipscomb, 1964) and further indicated that a mixture of 2,4-DEP + PCP controlled weeds well. Hauser and Parham (1964) reported that the best time to apply mixtures containing dinoseb was when the peanuts were cracking the ground or when the weeds were barely visible, whichever occurred first. This finding was confirmed by subsequent research in Oklahoma by Matthiesen and Santelmann (1971).

A report from Upchurch and Selman (1963) showed that a mixture of dinoseb + *N*-1-naphthylphthalmic acid (naptalam) was the most successful commercial treatment in North Carolina developed prior to 1963. However, mixtures containing dinoseb were not as effective in North Carolina as in other peanut areas. Upchurch and Worsham (1965) reported that the herbicides in their studies did not affect the commercial grade of peanuts. Previous data from Georgia (Hauser and Parham, 1964) suggested that neither commercial grade nor sensory characteristics were changed by herbicides.

Herbicide mixtures were utilized widely by peanut farmers during the 1960's especially in the southeastern states. For example, 2 of the most popular treatments in 1966 for peanuts in North Carolina were mixtures of either *N*,*N*-dimethyl-2,2-diphenylacetamide (diphenamid) or naptalam with dinoseb (Worsham and Perry, 1967). Rud (1968) reported from Virginia that when preplanting treatments were followed by mixtures at "cracking", the mixtures contributed more to overall weed control than did the preplanting treatments. In Georgia (Hauser, 1967), a mixture of herbicides applied at "cracking" increased the average yield of peanuts over a 5-year period. A report from North Carolina (Upchurch and Selman, 1968) indicated that dinoseb at 6.7 kg/ha applied as delayed preemergence treatments, controlled weeds better than dinoseb at lower rates in mixtures with other herbicides. From the southwestern United States Santelmann et al. (1963) and Santelmann and Matlock (1964) reported that most herbicides evaluated on peanuts over a 7-year period were satisfactory with particularly good control of weeds from mixtures of dinoseb with either 3-amino-2,5-dichlorobenzoic acid (chloramben) or 2,4-DEP applied at "cracking." A mixture of naptalam or 2,4-DEP with dinoseb controlled broadleaf weeds better than other postemergence treatments (Cargill et al., 1970). In later studies (Santelmann et al., 1967) 5 herbicides failed to consistently reduce the yield of peanuts, regardless of imposed variations in depth of planting or soil moisture. No herbicide evaluated in Oklahoma affected the market or organoleptic quality of peanuts.

During the 1950's and 1960's Texas panicum became a major pest for many peanut growers, especially in the Georgia-Florida-Alabama and southwestern peanut belts. The herbicide mixtures commonly used at this time did not control this grass. The herbicide α,α,α-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine (trifluralin), incorporated into soil before planting (Pieczarka et al., 1962), proved especially effective on annual grasses, including Texas panicum. It produced satisfactory results in Texas and Oklahoma (Santelmann et al., 1963; Boswell et al., 1968, 1969) on spanish peanuts. In Brazil (Leiderman et al., 1965; Leiderman and des Santos, 1967) trifluralin controlled certain weeds without damaging peanuts. However, in the southeastern states, unpublished data from several sources showed that trifluralin sometimes prevented normal fruiting of peanuts. Another substituted aniline, *N*-butyl-*N*-ethyl-α,α,α,trifluoro-2,6-dinitro-*p*-toluidine (benefin), was described (Guse et al., 1966). They reported that peanuts tolerated benefin better than trifluralin; and that, like trifluralin, it controlled many annual weeds, especially grasses, but that it would not control certain broadleaf weeds such as sicklepod and Florida beggarweed. Because of its safety on peanuts and its effectiveness on annual grasses, peanut farmers have accepted benefin. Another herbicide with similar weed control properties, 4-(methylsulfonyl)-2,6-dinitro-*N*,*N*-dipropylaniline (nitralin), appeared especially effective in Texas (Boswell et al., 1968) and, in addition, was evaluated in Oklahoma (Santelmann and Matlock, 1964) and in Alabama by Buchanan et al. (1969). The Alabama workers and Lipscomb and Wilcox (1967) in Florida also found that 2,3,5-trichloro-4-pyridinol (pyriclor) controlled many species of weeds. In Gambia (Ashrif, 1966) in preliminary experiments, 2,4-bis(isopropylamino)-6-(methylthio)-*S*-triazine (prometryn), diuron, and 3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea (linuron) controlled annual grasses without injuring peanuts.

Perennial nutsedges, among the world's worst weeds (Holm, 1969), became a major problem for many peanut growers between 1955 and 1965. Several factors promoted increasing infestations of nutsedge in peanuts, especially in the southeastern area. The shortage and high cost of hand labor made mechanical control unsatisfactory. Also, as herbicides helped bring many annual weeds under control and the use of cultivation lessened, nutsedge encountered decreased competition within the ecosystem. Increased mechanization, in general, contributed to the spread of both purple and yellow nutsedges.

None of the herbicides used by peanut farmers during the 1950's controlled nutsedge. The thiocarbamates, later intensively evaluated for controlling nutsedge, were first evaluated for use in peanuts by Burt (1959). He found that *S*-ethyl dipropylthiocarbamate (EPTC), *S*-propyl butylethylthiocarbamate (pebulate) and *S*-propyl dipropylthiocarbamate (vernolate) effectively controlled

certain annual weeds. These herbicides performed more effectively when incorporated into the soil than when sprayed on the soil surface.

Hauser and Parham (1964) and Hauser (1965) described the responses of nutsedge, sicklepod, and Texas panicum to EPTC, pebulate, and vernolate. The herbicides controlled these weeds most effectively when they were applied in subsurface layers between the peanut seed and the soil surface; however, layering increased injury to peanuts over that from incorporation. Later research showed that manipulation of herbicide placement (utilizing injectors or covered sweeps) and precision positioning of both the peanut seed and the herbicide substantially decreased injury sustained by peanuts from vernolate (Hauser and Parham, 1965, 1967; Hauser, 1966; Dowler and Hauser, 1970; Hauser et al., 1977). In fact, Georgia data (Hauser et al., 1969) averaged over 2 years and 2 soil types showed that peanuts yielded 14 % more after subsurface applications than after incorporation of vernolate.

Devices for the subsurface application of the relatively volatile thiocarbamates under field conditions have been described (Wooten and McWhorter, 1961; Holstun et al., 1963; McWhorter et al., 1966; Dowler and Hauser, 1970; Hauser et al., 1977).

In areas where peanuts are irrigated, the performance of benefin, nitralin, and vernolate incorporated into soil may be related to the irrigation method. Jordan et al. (1963) found that sprinkler irrigation produced better results than furrow irrigation with some herbicides.

Recently, due to intensifying cocklebur populations, research workers in the United States evaluated postemergence applications of 4-(2,4-dichlorophenoxy) butyric acid (2,4-DB) on peanuts and soybeans. McWhorter and Hartwig (1966) found low rates effective for controlling cocklebur in soybeans. Although Oram (1961) injured peanuts with 2,4-DB at 2.8 kg/ha, published (Boswell, 1971) and unpublished data from several U. S. locations show that peanuts can tolerate low rates of this herbicide. Also, earlier reports from Queensland by Rawson (1962, 1963) indicated that low rates of 2,4-DB were relatively safe on peanuts. When applied 6 or 7 weeks after emergence, at rates of 0.28 and 0.6 kg/ha, the mean yield reduction of peanuts was 0.45% for each 28 gm. of 2,4-DB applied compared to 3.5% for each 28 gm. of 2,4-D. Therefore, 2,4-DB was about 8 times as safe as 2,4-D when applied at these rates and stages of growth. However, Selman and Upchurch (1961) reported that low rates of 2,4-D appeared safe if applied within 20 days after planting peanuts.

The decade of the 1970's has been a period of refinement of procedures using both new and old herbicides as well as the introduction of some completely new herbicide chemistry. Dinoseb, which has been evaluated for weed control in peanuts since the early 50's, was intensively studied as a postemergence application treatment (Shaw et al., 1951; Helms, 1955). Hauser and Buchanan (1978) showed that this herbicide was highly effective in control of Florida beggarweed and moderately effective in control of sicklepod when applied in sequence at relatively low dosages.

Considerable research was directed in this decade toward the evaluation of herbicides applied as preemergence treatments (Buchanan et al., 1969). Results of the research led to labeling and widespread use of alachlor. Oxadiazon also has been extensively evaluated, but to date is not labeled for use in peanuts (Buchanan et al., 1977; Buchanan et al., 1978).

Failure to satisfactorily control several major, tall-growing broadleaf weeds and the associated development of the recirculating sprayer (Dale, 1980a,b) led to considerable interest in this technique for control of certain weeds in peanuts. Hauser and Buchanan (1978) clearly demonstrated the usefulness and desirability of this weed control technique in peanuts.

Technical Description of Herbicides Registered for Peanuts

Registration and labeling of chemical treatments for weed control in peanuts have been accomplished through extensive research and development efforts by state, federal and industry scientists. Registration of herbicides is done in accordance with the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as amended. The Environmental Protection Agency (EPA) has the basic authority for registering all pesticides, though states share that authority and may be more restrictive (but not less) than the federal agency (EPA, 1980). The EPA may also authorize a state agency to register a pesticide for special local needs within the state and that registration may become permanent unless EPA objects within 90 days.

As a result of cooperative research and development, the following herbicides (see Table 5 for nomenclature) were registered for use on peanuts as of January 1, 1981: (a) alachlor, (b) benefin, (c) bentazon, (d) chloramben, (e) dinoseb, (f) diphenamid, (g) metolachlor, (h) naptalam, (i) trifluralin, (j) vernolate, (k) 2,4-DB, and combinations involving mixtures of certain individual herbicides. The authors have included technical information on acifluorfen, glyphosate, and oxadiazon in anticipation that these herbicides will receive registration for use on peanuts in the near future. Because of constant evaluation and development, some registrations may be cancelled and other treatments may be registered; thus any list soon becomes obsolete. Therefore, the reader is cautioned that some statements in this section may change. Guidance as to actual use of these herbicides should be obtained from current manufacturers' labels before use.

Acifluorfen. The technical material is a brown, aqueous, viscous solution containing 45% a.i. and is infinitely soluble in water at 25 C. For herbicide purposes, it is formulated as a sodium salt solution. Acifluorfen is generally applied as a postemergence spray; however, at increased rates it exerts preemergence activity. Postemergence rates are from 0.14 to 1.12 kg/ha and preemergence rates are from 0.6 to 2.24 kg/ha.

This contact herbicide shows very little movement from root or foliar application. Light is required for herbicidal activity. In soil, acifluorfen shows very little leaching and a half life of 30 to 60 days. This herbicide readily photodecomposes to non-herbicide products.

Alachlor. The pure compound is an odorless, cream-colored solid at room temperature, with a water solubility of 242 ppm at 25 C. It is formulated either as an emulsifiable or as a granule.

Alachlor is applied primarily as a preemergence treatment at rates of 2.2 to 3.4 kg/ha. Rain or irrigation within 5 to 7 days after application is necessary for best results. Under reduced moisture, soil incorporation is considered advantageous. Shallow cultivation, when necessary to remove escaped weeds, will not destroy the herbicidal activity. Alachlor is also effective as a "cracking stage" or early postemergence treatment in combination with dinoseb and dinoseb plus naptalam. The combination appears to be superior to any of these compounds used alone for control of prickly sida, pigweed, Florida pusley, sicklepod, copperleaf, goosegrass, morning glory, and Florida beggarweed.

Alachlor is subject to microbial breakdown and at rates of 2.3 to 3.4kg/ha should not persist in the soil (in herbicidal concentrations) more than 6 to 10 weeks. Microbial breakdown accounts for approximately 90%, and chemical breakdown accounts for approximately 10%. However, it is somewhat mobile in the soil, especially sandy soils low in organic matter.

Benefin. The pure compound is an odorless yellow orange crystalline solid with a water solubility less than 1 ppm. It is formulated as an emulsifiable concentrate or as a granule.

Benefin has preemergence activity but because of its volatility and ability to photodecompose, it is incorporated into the soil at time of application or within the time specified on the product label. Under most conditions, the power take-off driven rotary tiller, double disk, rolling cultivator or other similar equipment effectively mixes benefin with the soil. Benefin is used at rates of 1.25 to 1.6 kg/ha with the lower rate on sandy soils and higher rates on soils having high exchange capacities. Soil particles strongly absorb benefin; therefore, it resists leaching. Microbial breakdown occurs gradually in soils. Rates of 1.25 to 1.6 kg/ha usually control weeds for 4 to 5 months in temperate zones.

Bentazon. The pure compound is an odorless, white, crystalline solid at room temperature, with a water solubility of 500 ppm at 20 C. Bentazon is formulated as a water soluble sodium salt and is packaged as a solution.

Table 5. Nomenclature of herbicides registered for weed control in peanuts (as of January 1, 1981)[a].

WSSA Common Name	Trade Name as of 6/1/80	Formula
acifluorfen[b]	Blazer	5-[2-choro-4-(trifluoromethyl)-phenoxy]-2-nitrobenzoic acid
alachor	Lasso	2-chloro-2,6-diethyl-*N*-(methoxymethyl)acetanilide
benefin	Balan	*N*-butyl-*N*-ethyl-α,α,α-trifluoro-2,6-dinitro-*p*-toluidine
bentazon	Basagran	3-isopropyl-1*H*-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide
chloramben	Amiben	3-amino-2,5-dichlorobenzoic acid
dinoseb	various names	2-*sec*-butyl-4,6-dinitrophenol
diphenamid	Dymid & Enide	*N*,*N*-dimethyl-2,2-diphenylacetamide
glyphosate[b]	Roundup	*N*-(phosphonomethyl)glycine
metolachlor	Dual	2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide
naptalam	Alanap	*N*-1-naphthylphthalamic acid
oxadiazon[b]	Ronstar	2-*tert*-butyl-4-(2,4-dichloro-5-isoproxyphenyl)-Δ^2-1,3,4-oxadiazolin-5-one
trifluralin	Treflan	α,α,α-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine
vernolate	Vernam	*S*-propyl dipropylthiocarbamate
2,4-DB	various names	4-(2,4-dichlorophenoxy)butyric acid

[a]Trade names are used solely to provide specific information. Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the United States Department of Agriculture or by the Alabama, Georgia, or Oklahoma Agricultural Experiment Stations, and does not imply its approval to the exclusion of other products that may also be suitable.

[b]At the time of developing this table, these products were not registered by EPA for use in peanuts. Current labels should be consulted before use.

Bentazon is usually applied at rates of 0.84 to 2.24 kg/ha as a postemergence spray for broadleaf weed control. There is some activity on yellow nutsedge. Bentazon activity is primarily by contact action with very little acropetal or basipetal movement after foliar applications. Bentazon is rapidly utilized by soil bacteria and fungi and its persistence in soil generally is undetectable within 6 weeks.

Chloramben. The pure compound is a white amorphorous odorless powder with a water solubility of 700 ppm. For herbicidal use, it is formulated as an ammonium salt or as granules.

Chloramben is applied at rates of 2.24 to 3.36 kg/ha before weed and crop emergence. For best effectiveness, moisture should be available to move the material into the zone of germinating weeds. Under conditions of deficient soil moisture, shallow cultivation may be necessary to destroy germinated weed seedlings. This cultivation will not interfere with the herbicidal action when rains do occur.

Chloramben inhibits root development of seedling weeds. It moves readily following heavy rains particularly in sandy soils. It is subject to microbial breakdown in soils with the average persistence being about 6 to 8 weeks from applications of 2.24 to 3.36 kg/ha.

Dinoseb. The technical chemical is a dark brown solid or dark orange liquid with low water solubility and a pungent odor. Dinoseb is highly toxic to fish and moderately toxic to birds. For herbicidal use in peanuts, the material has been formulated as alkanolamine salts (of the ethanol and isopropanol series) and as a triethanolamine salt, both of which are water soluble.

Dinoseb controls weeds both as preemergence and postemergence treatments. Rates vary from 0.84 to 13.4 kg/ha with the highest rates (6.7 to 13.4 kg/ha) generally required for preemergence treatment to achieve consistent residual action in soil. The current use of dinoseb in peanuts is generally as a "cracking" or as an early postemergence spray for the control of seedling weeds (at rates of 0.84 to 3.36 kg/ha). Various formulations of dinoseb or combinations with other herbicides are available.

Direct cell necrosis is the primary mode of action involved after postemergence treatment. Essentially no translocation occurs after application. Dinoseb leaches readily in soils, but there is some evidence of partial adsorption in certain organic and clay soils. Some losses occur via steam distillation under specific conditions of soil acidity, high temperature, and surface soil moisture. Microbial breakdown in soil prevents buildup and suggested rates persist in concentrations phytotoxic to weeds from about 2 to 4 weeks, depending on weather conditions and the rate applied.

Diphenamid. The technical material is a white solid which is soluble in water at 360 ppm. It is formulated as a wettable powder or as a water dispersible concentrate.

Diphenamid is ordinarily sprayed on the surface of the soil without incorporation but shallow soil incorporation may increase its effectiveness under dry conditions. On peanuts, diphenamid may be applied at planting, at cracking, or up to 7 days after cracking; with the latter 2 applications, diphenamid should be combined with dinoseb for control of emerging weeds. Absorption is mainly through the roots with subsequent translocation through roots, stem, and leaves. Foliar absorption is very limited. Sub-lethal concentrations in susceptible species severely inhibit normal root development. Diphenamid is not adsorbed to soil colloids. It leaches quite rapidly in sandy soils but more slowly in loams and clay soils. The usual rates for peanuts are 2.24 to 3.36 kg/ha but rates up to 6.7 kg/ha are registered. Under warm moist conditions, persistence at herbicidal levels is from 3 to 6 months, but under low rainfall, diphenamid may persist longer. Micro-organisms appear to play a significant role in soil degradation.

Glyphosate. The technical material is an odorless, white solid with a water solubility of 12,000 ppm at 25 C. Glyphosate is formulated as a solution of the isopropylamine salt.

Glyphosate is a broad spectrum herbicide, relatively non-selective, and effective on many deep-rooted perennial species and on annual and biennial species of grasses, sedges, and broadleaved weeds. Applications of glyphosate for weed control in peanuts are made as foliar sprays to weeds prior to ground preparation or planting or after harvest. Rates of use vary with species to be controlled. Normally from 0.34 to 1.12 kg/ha acid equivalent (ae) will control annual species. Perennials will require rates from 1.12 to 4.5 kg/ha ae with the majority of perennials requiring 1.7 to 2.24 kg/ha ae. Glyphosate is absorbed through foliage and translocated throughout the plant. Strong adsorption to soils results in very little leaching. Because it is adsorbed strongly, glyphosate causes little phytotoxicity to plants when applied to the soil. Microbial degradation is the major cause for glyphosate decomposition in soil. Soil residues are near or below 10% of that applied within a growing season.

Metolachlor. The pure compound is an odorless, white to tan liquid with a water solubility of 530 ppm at 20 C. For herbicide use it is formulated as an emulsifiable concentrate.

Applications may be made preplant with shallow incorporation or preemergence at rates of 1.7 to 3.36 kg/ha. Under dry conditions, a shallow incorporation will increase the degree of weed control.

Germinating monocot seedlings absorb most of the metolachlor through the shoots just above the seed, while dicots seem to absorb the herbicide through both shoots and roots.

Metolachlor is more readily absorbed to muck or clay soils than to soils of low clay and organic matter content. Organic matter is the main soil constituent determining the leaching behavior. When organic matter content approaches 2.0%, no significant leaching would be expected. The soil half life is 15 to 50 days depending on soil type and environmental conditions. No buildup following repeated annual applications is expected.

Naptalam. The technical compound is a purple crystalline powder with an unpleasant odor and a water solubility of 200 ppm. It is formulated as a sodium salt which is highly soluble in water.

Naptalam is usually applied as a preemergence treatment and moisture is necessary for activation. The most common rate is 4.5 kg/ha, but the dosage range is 2.24 to 6.7 kg/ha with the heavier rate for soils of higher base exchange capacities.

The most widespread use of naptalam in peanuts has been in combination with dinoseb. The mixture is applied when the peanut plants are beginning to crack through the soil. This stage is commonly referred to as the "at cracking" stage.

Naptalam leaches rapidly in highly porous or silt loam soils of extremely fine texture. Heavy rains after application may cause leaching and result in crop injury. It is relatively nonvolatile and photostable.

Oxadiazon. The technical material is an odorless, white, crystalline powder with a water solubility of less than 1 ppm at 20 C. For herbicide use, it is formulated as an emulsifiable concentrate or as a granule.

Oxadiazon is generally applied at rates of 0.84 to 4.5 kg/ha as a preemergence application; however, there is some activity as an early postemergence treatment. This herbicide controls a broad spectrum of weeds and has shown activity on some of the more troublesome weeds in peanuts including copperleaf, Florida beggarweed, Texas panicum, and others. This herbicide is not actively absorbed by foliage except with extremely susceptible species. Oxadiazon is strongly absorbed by soil colloids (and humus) and very little leaching occurs.

Trifluralin. Technical material is an orange crystalline solid with very low solubility in water. It is formulated as an emulsifiable concentrate and as granules.

Trifluralin controls weeds best when incorporated in the soil. It volatilizes and is degraded by sunlight unless incorporated. Application is either before or after planting the crop, but it is not effective unless it is applied preemergent to the weeds. The rate used in peanuts is 0.5 kg/ha and this rate will generally control weeds for 4 to 6 months. It affects weed seedling emergence and the associated physiological growth processes. There is no significant absorption or translocation in crops grown in treated soil.

Trifluralin is not easily leached through the soil as it is strongly absorbed on clay colloids and organic matter. Microbial actions play a significant role in the breakdown of the compound in soils. Trifluralin is registered only for spanish peanuts grown in Oklahoma and Texas.

Vernolate. The technical material is a liquid with a solubility of about 90 ppm in water at 20 C. Vernolate exerts preemergence effects on germinating weeds but is much less effective if sprayed on the soil surface than if incorporated or injected. Farmers commonly incorporate vernolate with disk harrows. Application rates are from 2.24 to 5 kg/ha. Vernolate is absorbed onto dry soil but may leach after hard rains. Microbial breakdown is significant in detoxication of vernolate in soil. Vernolate is readily lost from the soil by volatilization when the soil surface is wet at the time of application. When applied at 2.24 to 2.8 kg/ha, vernolate does not persist in soil long enough to interfere with rotational cropping. The half life in moist loam soil at 21.1 to 26.6 is approximately 1.5 weeks.

2,4-DB. In the pure state, 2,4-DB is an odorless, white, crystalline solid with essentially no water solubility. As a herbicide, 2,4-DB is formulated as an amine salt and low volatile ester; it is used as a postemergence treatment for the control of broadleaf weeds. The herbicide is foliar absorbed and readily translocated to meristematic areas of metabolic activity. As applied, 2,4-DB is not phytotoxic, but is beta oxidized to 2,4-D by susceptible species. It has essentially no soil activity.

Toxicology of Herbicides Registered for Peanuts

Before a herbicide can be registered for use in a crop, a registrant must supply EPA with data and information involving several criteria. One criterion is toxicological information. Sufficient information must be provided to assure that unreasonable adverse effects will not result from use according to the label directions or according to commonly accepted practices.

Toxicological information provided also must be adequate to permit classification of the product as to toxicity according to the scheme shown in Table 6. If the product falls in Toxicity Category I, it must bear the signal word DANGER on the front panel; also POISON in red and a skull and crossbones, unless it is in Category I only because of skin or eye effects. Toxicity Category II requires the signal word WARNING and Toxicity Categories III and IV require CAUTION. In addition, an appropriate statement of a practical treatment in case of human poisoning must be shown on the label of pesticides in Toxicity Categories I, II, and III.

Toxicological properties are determined early in the developmental stages of pesticides. Generally, they include acute, subacute, and chronic oral toxicity in at least 2 species of experimental animals. They also may include reproductive tests, and/or tests for carcinogenicity, teratogenicity, and mutagenicity depending upon the structure of the compound, the uses contemplated, and/or the results of the chronic studies. Similar data concerning inhalation and dermal routes may be required for registration but not for tolerances. A common indicator is the acute toxicity and is expressed as LD_{50} (lethal dose). This term represents the single dosage required to kill 50% of the test species when the pesticide is administered by mouth or in some cases injected directly into the stomach. This dosage is expressed as milligrams of compound per kilogram of body weight. Milligrams per kilogram can frequently be better understood if they are considered as parts per million (ppm). The acute toxicity or LD_{50} evaluations are initially performed on animals (usually rats and mice). More stringent tests are now being conducted on a number of other test species

Table 6. Toxicity categories of pesticides.

Hazard Indicators	I	II	III	IV
Oral LD_{50}	Up to and including 50 mg/kg	From 50 through 500 mg/kg	From 500 through 5,000 mg/kg	Greater than 5,000 mg/kg
Inhalation LC_{50}	Up to and including 0.2 mg/liter	From 0.2 through 2 mg/liter	From 2.0 through 20 mg/liter	Greater than 20 mg/liter
Dermal LD_{50}	Up to and including 200 mg/kg	From 200 through 2,000 mg/kg	From 2,000 through 20,000 mg/kg	Greater than 20,000 mg/kg
Eye Effects	Corrosive; corneal opacity not reversible within 7 days	Corneal opacity reversible within 7 days; irritation persisting for 7 days	No corneal opacity; irritation reversible within 7 days	No irritation
Skin Effects	Corrosive	Severe irritation at 72 hours	Moderate irritation at 72 hours	Mild or slight irritation at 72 hours

such as dogs, rabbits, monkeys, and birds. For determining the toxicity of pesticides on aquatic organisms, the term LC_{50} (lethal concentration) is used. This denotes the median lethal concentration or concentration of toxicant necessary to kill 50% of the organisms being tested and it is usually expressed in ppm.

Subacute toxicity is determined by administering a pesticide at lower than lethal dosages over several days or weeks and this is expressed as subacute LD_{50}. Long-term oral administration of trace amounts is used for determining the chronic toxicity. Frequently, this evaluation also considers the effects on future offspring or generations.

Additional supporting information is now determined in tests concerning skin, eye, and inhalation exposures to establish potential hazards due to pesticides. Table 7 lists the relative toxicity as measured by the LD_{50} of herbicides registered for use on peanuts (WSSA Herbicide Handbook, 1979). Other common materials have been included for comparison. If a residue remains in or on the plant after treatment, registration will depend on evidence that will establish that the residue is generally safe, exempted from tolerance requirements, or is within limits of amounts declared safe. A petition for a tolerance must include evidence of levels of residues of the active or inert ingredients or their metabolites, impurities, or breakdown products that can be expected to remain on the crop at harvest or on the processed food at the point of sale. In general, a tolerance will not be granted for a level higher than the maximum, which can be expected to result from recommended use of the pesticide. If a specific interval is needed between the last application and harvest in order to ensure meeting this level, then that preharvest interval must be indicated on the label of the pesticide.

Table 7. Relative toxicity of several herbicides and certain other compounds to rats.

Common Name or Designation	Acute Oral[a] LD_{50} (mg/kg)	Toxicity[b] Rating
dinoseb	58	I
gasoline	150	II
diphenamid	970 ± 140	III
bentazon	1,100	III
aspirin	1,200	III
acifluorfen	1,300	III
naptalam	1,770	III
vernolate	1,780	III
alachlor	1,800	III
2,4-DB	1,960	III
metolachlor	2,780	III
table salt	3,320	III
chloramben	3,500	III
glyphosate	4,320	III
oxadiazon	>8,000	IV
benefin	>10,000	IV
trifluralin	>10,000	IV

[a]From Herbicide Handbook of the Weed Science Society of America. Fourth edition. Weed Science Society of America, Champaign, IL.
[b]Numerical toxicity value based on the classification of pesticides under FIFRA as amended.

Toxicological information accompanying a petition for a tolerance must be adequate to assure reasonable safety to humans consuming food containing the maximum level permitted.

A petition for a tolerance must be accompanied by a detailed description of an analytical technique adequate for detecting the requested level of residues on the crops or foods involved. Possible interactions of the residue with other factors, such as concurrent illness, age, pregnancy, or diet, will also be considered. The details of tests that must be performed to provide the toxicological information will vary depending upon the characteristics of the chemical involved.

Finally, the 1972 amendment to FIFRA required that starting in 1975, applicants for registration must also indicate whether they want their product registered for general use (no restrictions other than consistent with the labeling) or for restricted use. If for restricted use, the product can be applied only by or under the supervision of a certified applicator or in accordance with other restrictions as established by regulations.

Weeds Controlled by Herbicides Registered for Peanuts

A list of weeds which a herbicide controls must appear on the product label of a registered herbicide. Efficacy information must be sufficient to assure the EPA that the product will in fact produce the results claimed or implied in the labeling. Labels frequently contain information about the size or stage of weed growth at which optimum control can be obtained. Weed sizes or developmental stages of weeds other than those specified on the label will frequently result in reduced weed control. Suggested herbicide rates, number of herbicide applications, and approved combinations with other pesticides, additives, or fertilizers will also be given on this label. Conditions resulting in reduced weed control or crop injury will also appear in the precautionary statements.

Table 8 contains a partial list of weeds controlled or suppressed by the herbicides registered for use on peanuts. The authors of this chapter have included information on acifluorfen, glyphosate, and oxadiazon in anticipation that these herbicides will receive registration for use on peanuts in the near future. Most of the information contained in Table 8 was obtained from manufacturers' labels; however, control of some species was documented from comments by research scientists evaluating these herbicides.

Effects of Environmental Conditions on Activity and Persistence of Herbicides Used in Peanuts

Herbicide activity is directly influenced by environmental conditions. Thus, knowledge of how the environment affects herbicide performance is essential to achieving successful results with these materials. Most herbicides used for weed control in peanuts are applied to the soil and their fate is ultimately determined by soil factors (Figure 1). Various soil properties such as moisture, temperature, fertility, and pH influence herbicide activity and persistence through their effects on herbicide movement, microbial breakdown, adsorption onto colloids, volatilization, plant uptake, and other factors.

Table 8. Summary of weeds controlled by designated herbicides based on information derived from the manufacturers' labels and from various other sources.

Weed Species Common Name	Herbicides													
Annuals:	acifluorfen	alachlor	benefin	bentazon	chloramben	dinoseb[b]	diphenamid	glyphosate[c]	metolachlor	naptalam	oxadiazon	trifluralin	vernolate	2,4-DB
Bristly starbur	X			X				X						
Broadleaf signalgrass		X[a]	X					X	X		X	X		
Carpetweed	X	X	X	X	X	X	X	X	X	X	X	X	X	
Cocklebur	X			X		X		X		X				X
Copperleaf	X	X						X			X			X
Crabgrass	X	X	X		X	X	X	X	X	X	X	X	X	
Crotons	X							X			X			
Florida beggarweed	X	X			X	X	X	X		X	X			
Florida pusley	X	X	X		X	X	X	X	X	X	X	X	X	
Foxtails	X	X	X		X	X	X	X	X	X	X	X	X	
Goosegrass		X	X		X	X	X	X	X	X	X	X	X	
Johnsongrass (from seed)	X	X	X		X		X	X	X	X		X	X	
Lambsquarter	X	X	X	X	X	X	X	X		X	X	X	X	X
Morning glories	X			X		X		X			X		X	X
Panicum, fall	X	X	X		X		X	X	X		X	X		
Panicum, Texas			X					X			X	X		
Pigweed	X	X	X		X	X	X	X	X	X	X	X	X	X
Purslane, common	X	X	X	X	X	X		X	X	X	X	X		
Ragweed, common	X	X		X	X	X		X		X	X		X	X
Sandbur	X	X	X					X	X		X	X		
Sicklepod						X		X					X	
Sida, prickly	X	X		X	X			X			X			X
Smartweed	X	X		X	X			X			X			X
Perennials:														
Honeyvine milkweed				X										
Horsenettle				X										
Johnsongrass				X										
Nutsedge, yellow		X		X				X	X				X	
Nutsedge, purple				X										
Silverleaf nightshade								X						X

[a]"X" indicates that the species listed is normally controlled or suppressed by rates of herbicide registered for use in peanuts.
[b]Applies only to contact kill by dinoseb at rates of 1.5 to 6 lb/A.
[c]Postemergence applications only.

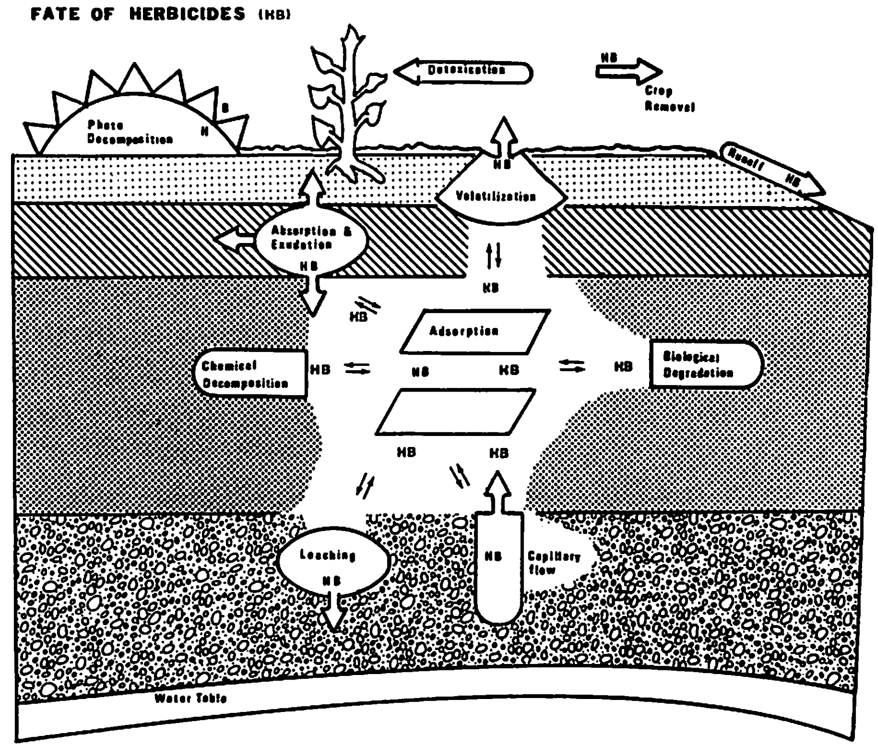

Fig. 1. Processes influencing the behavior and fate of herbicides in the environment. Degradation processes are characterized by the splitting of the herbicide (HB) molecule. Transfer processes are characterized by the herbicide (HB) molecules remaining intact. (Adapted from Weber et al., 1973).

Soil Moisture. Weed control with herbicides applied to soil varies widely with the amount of moisture available. Rain or irrigation is usually needed to activate most of these herbicides, and this interaction of rainfall with activity is one of the most important factors controlling the field performance of herbicides applied as preemergence treatments. In laboratory experiments Cooke (1966) found that chloramben required 1.3 cm. of simulated rain for activation. High amounts of rain leached chloramben from the surface layers of the soil and thus lowered weed control. Burnside and Lipke (1962) found that as the chloramben rate was increased, less water was required for optimum weed control. Researchers reported similar results for most other preemergence treatments.

Most research with moisture and rain has involved the influence of different soil moisture levels on the activity of herbicides. Knake et al. (1967) reported that shallow incorporation of chloramben increased effectiveness under low moisture conditions. Hill et al. (1968) reported that peanut root injury was significantly increased when they used chloramben under very dry conditions. According to Stickler et al. (1969) chloramben activity increased linearly with increasing moisture through the entire range of soil moistures from 25 to 37%, while trifluralin activity decreased (Figure 2). Upchurch et al. (1968), working with several herbicides incorporated in soil for weed control in peanuts,

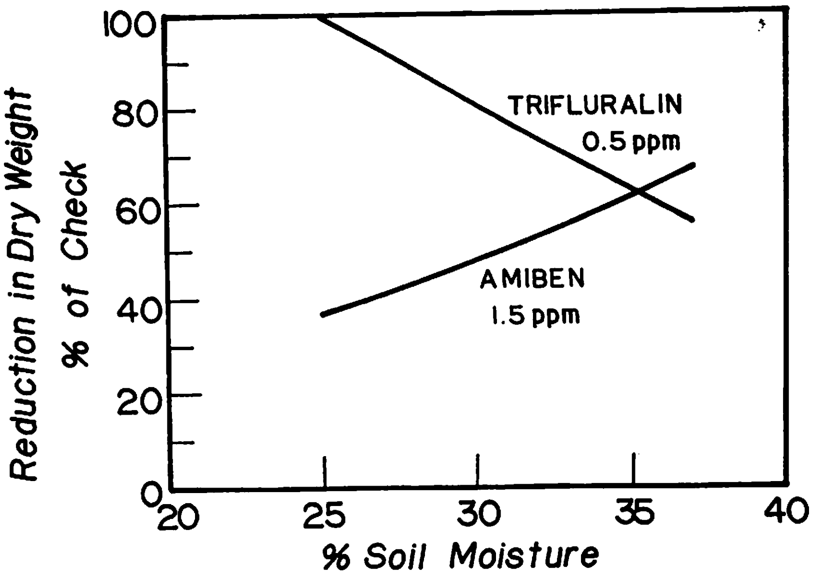

Fig. 2. Effect of various soil moisture levels on herbicide effectiveness. Herbicide concentrations are expressed as parts of herbicide per million of oven-dry soils (Adapted from Stickler et al., 1969).

found that in some instances weeds were controlled poorly with vernolate. They commented that the relatively poor performance of the standard treatment with vernolate was correlated with a low average minimum temperature and a low amount of rain during the first 30 days after treatment. Hauser and Parham (1964) found differences among vernolate treatments most pronounced when dry weather followed the vernolate application; under these conditions poorer weed control was obtained following incorporation. Hauser et al. (1969) also reported that both temperature and rain influenced the activity of vernolate, but lack of adequate rain during the month after treatment seemed particularly important in decreasing the weed control by vernolate.

More research evaluating herbicide-soil moisture level interactions has been conducted with trifluralin than with any other herbicide. Since benefin is closely related to trifluralin, it is logical to assume that soil moisture would affect benefin in the same manner as trifluralin. Hill et al. (1968) found trifluralin injured peanut roots most when the soil was driest. Strickler et al. (1969) found that weed control response to trifluralin decreased linearly with increasing moisture, which contrasts to the results obtained with chloramben.

Sweet et al. (1966) found no consistent benefit from incorporation of trifluralin compared with surface application as long as soil moisture was adequate. However, Knake et al. (1967) reported that under 3 different moisture conditions shallow incorporation of trifluralin was beneficial at all moisture levels used.

Moisture also influences persistence of trifluralin in the soil. Bardsley et al. (1967) reported that vapor losses of trifluralin were greater from a soil at a maximum moisture retention capacity than from a soil at field capacity when the trifluralin was applied at equal rates to the soil surface. This was attributed to

the greater proportion of free liquid available for vapor loss under high moisture activity and to competition of water with trifluralin for adsorption sites. Placement of trifluralin 3.8 cm below the soil surface resulted in a very low vapor loss, regardless of the moisture regime used. Savage and Barrentine (1969) reported that volatilization was an important mode of trifluralin dissipation from the soil. Trifluralin volatilization decreased with increasing depth of incorporation, and persistence increased with deep incorporation when compared to shallow incorporation or surface application.

Savage (1978) reported that the dissipation rate of trifluralin was significantly increased when the soil was flooded. Volatilization was reduced by flooding when compared to volatilization from the same soil with a moisture content equivalent to field capacity. The effect of flooding on dissipation rates is apparently not due to increased volatilization.

Probst et al. (1967) reported that trifluralin was lost rapidly from a wet Brookston soil (200% field capacity) (Figure 3). Within 10 days, 50% of the added trifluralin disappeared and after 24 days, 84% disappeared. Loss of trifluralin from the soil was considerably slower at 50 and 100% of field moisture capacity levels. Loss from air dry soil was very slow.

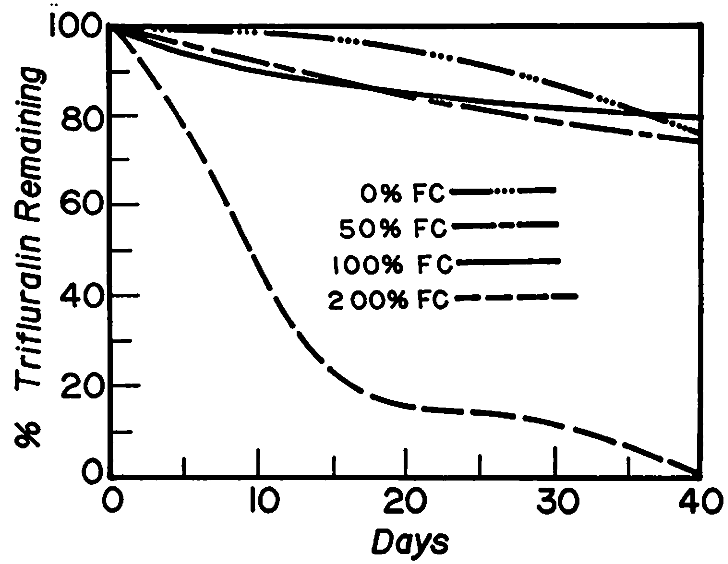

Fig. 3. Trifluralin degradation in Brookston soil of differing field moisture capacity (Reprinted from Probst et al., 1967). Copyright 1967 American Chemical Society.

Parr and Smith (1971) reported that degradation of trifluralin was more rapid and extensive in substrate-amended soil under anaerobic conditions. This also occurs when compared with well-aerated systems, and following the order of moist (1/3 bar) anaerobic > flooded anaerobic > moist aerobic. Degradation in these environments after 20 days was 99, 45, and 15%, respectively. Miller et al. (1975) reported that benefin and trifluralin residues were confined to the tilled zone of soil (upper 30 cm) and about 80% of the residue was in the upper 15 cm of soil. According to Burnside (1974) repeated annual applications of trifluralin at a normal rate did not cause significant buildup in the soil over a 4-year period. Analyses of soil samples from 107 sites, by Parka and

Tepe (1969) indicated that trifluralin does not accumulate with repeated annual applications, and that a steady and continuous decline in the level of trifluralin present in the soil occurred with time.

Stoller and Wax (1977) reported that at normal use rates, trifluralin, profluralin and benefin did not show residual activity to wheat (*Triticum aestivum* L.) planted 5 months after application or to corn (*Zea mays* L.) planted 12 months later.

The influence of rain and soil moisture on dinoseb appears quite variable depending on whether dinoseb is used to produce an immediate burn, residual weed control, or both. Davis (1956) reported that rain may leach dinoseb from the surface, thereby decreasing the kill of emerging plants by vapor burn. A moderate rain 3 or 4 days after emergence increased vapor activity and the kill of weeds. Davis et al. (1954) and Dowler et al. (1958) found that the leaching of dinoseb was proportional to the amount of water applied, and that the amount of leaching varied with soil type. Hauser and Parham (1964) reported that, in general, mixtures of dinoseb applied as ground-cracking treatments were most effective if sprayed on a dry soil surface with no subsequent rain for several days or more. Poorest results occurred when mixtures were applied on wet soils with no rain subsequently for several days to several weeks.

Temperature. Temperature, both of the air and soil, strongly influences the activity and persistence of herbicides. Hill et al. (1968) reported that soil temperature variations significantly affected injury to roots of peanuts by chloramben. The amount of injury occurring at 32 C was significantly less than that which occurred at both 21 C and 38 C. Schliebe et al. (1965) reported that temperature had little influence on dissipation of chloramben by volatilization.

Dowler and Hauser (1969) reported that at a soil temperature of 23 C, trifluralin reduced plant growth significantly regardless of soil type, while at 32 C trifluralin affected growth very little. This agrees with the results of Hill et al. (1968), who reported peanuts were injured less by trifluralin if the soil temperatures were in the 26 to 32 C range. Hawxby et al. (1972) reported that the accumulation of trifluralin in peanut roots at 24 hours after exposure to trifluralin was greatest at 21 C and decreased at higher temperatures up to 38 C. The amounts of trifluralin translocated and accumulated in hypocotyls, tops, and cotyledons were small but generally increased with temperature.

Probst et al. (1967) found that the disappearance of trifluralin from soil was faster at 32 C than at 21 C. They concluded that trifluralin degradation is temperature dependent and proceeds more rapidly in a non-sterilized soil. This indicated that part of the breakdown of trifluralin in the soil is by microorganisms. Messersmith et al. (1971) reported that trifluralin breakdown generally increased in moist soil as soil temperature increased through the range of 20, 25, 35 C.

The influence of soil temperature on vernolate activity is similar to that with trifluralin. Less crop injury occurred at moderate soil temperatures from 27 to 32 C than at more extreme temperatures (Dowler and Hauser, 1969; WSSA Herbicide Handbook, 1979). Gray and Weierich (1968) reported that the rate of loss of vernolate from a moist soil increased with rising temperature.

The influence of air temperature on the activity of dinoseb varies depending upon the temperature involved, and upon whether the temperature variable is imposed before or after treatment. Davis (1956) reported that a relatively small increase in temperature from 29 to 35 C substantially increased the percentage of plants killed by dinoseb. Meggitt et al. (1956) reported that the activity of dinoseb increased as temperature after treatment increased from 15 C to 35 C. Dinoseb was less phytotoxic under growing temperatures of 21 and 32 C prior to treatment than with temperatures of 21 and 26 C. In general, field results with dinoseb show that as temperatures increase, particularly above 30 C, there is greater possibility of injury to the peanuts, but with an accompanying increase in weed control.

Soil Fertility Levels. Few reports were found describing the influence of soil fertility levels on the activity of herbicides used in peanuts. Walker and Jones (1969) reported a highly significant phytotoxic interaction between trifluralin and nitrogen at rates of 1 to 4 ppm of trifluralin and of 100 to 400 ppm of nitrogen. Recoverable trifluralin increased with the higher nitrogen concentration. They also found an interaction between trifluralin and selected nitrate and chlorine salts and concluded that synergistic effects between trifluralin and salts were due to the interdependence of trifluralin and the anions present. In particular, high levels of sodium nitrate caused a significant phytotoxic interaction with recommended rates of trifluralin. Miller (1968) reported no detrimental interaction between nitrogen or phosphorous fertilizers and trifluralin. In preliminary work Doll and Meggitt (1969) found that chloramben caused less plant injury as more nitrogen was added to the soil and suggested that the uptake mechanism of chloramben may be linked with plant metabolism in such a way that it becomes less lethal as the plant responds to nitrogen. Variations in available phosphorous and potassium did not cause significant effects.

Soil pH. Herbicides react differently under various soil acidity conditions. The pH of the soil may influence both phytotoxicity and persistence of herbicides (Selman and Upchurch, 1963). In general, the ionization of the herbicide in the soil will vary widely with different pH levels. For instance, Corbin (1967) reported that vernolate was more persistent at a pH of 4.3 than at a pH of 7.5. The soil pH may affect vapor losses of herbicides in 2 ways. First, pH influences adsorption and desorption of the herbicides on soil particles. Secondly, within the pH range encountered in natural soils, some herbicides vary from an ionized form to a non-ionized form. In the spring of 1952, when dinoseb vapors injured or killed many hectares of emerging cotton, such injuries did not occur on limed soils. Davis and Davis (1954) found that the vapor injury to plants from dinoseb was prevented in soils of high lime content. Dowler et al. (1958) reported similar results with some reduction in dinoseb activity occurring as soil pH approached neutrality, but indicated some variation in that the greatest effect was at pH 5 in one soil, pH 7 in another, and pH 6 in still another. At a low pH, dinoseb was in a volatile, non-ionized form. When the pH of the soil increased, dinoseb ionized to a less volatile form. Thus, the ionic characteristics of some herbicide molecules vary with pH causing different degrees of absorption in the soil. Selman and Upchurch (1963) reported that dinoseb decreases in toxicity as soil pH increases.

Work involving soil pH in the detoxification of herbicides in soil was reported by Corbin and Upchurch (1967) from North Carolina. Vernolate caused striking differences between test plants growing in soil with pH 4.3 or 7.5. A pH level of 7.5 in the soil appeared optimum for microbial growth and for herbicide inactivation. Inactivation at lower pH levels (4.3 and 5.3) was much slower. However, chloramben detoxification was not affected by pH. Miller (1968) reported that lime did not significantly influence the effect of trifluralin on plant growth.

Soil Organic Matter Content. The major influence of soil organic matter on herbicide activity and persistence appears to be through its effects on the adsorption of the herbicide in the soil. Most herbicides are affected similarly by organic matter in the soil as illustrated by Upchurch and Mason (1962), who also reported that the capability of organic matter to inactivate a herbicide increases on a percentage basis with an increase in organic matter concentration. For example, they reported that the amount of dinoseb required to reduce growth 50% increased rapidly as the soil organic matter also increased.

Grover (1974), studying the relative adsorption of several herbicides, including trifluralin, on various adsorptive surfaces, reported that the herbicides were strongly adsorbed with the following general trend: activated charcoal > peat moss > wheat straw-cellulose triacetate >cation exchange resin > anion exchange resin > silica gel-cellulose power > kaolinite-montmorillonite. Bardsley et al. (1968) indicated that the addition of organic matter to soil influenced the persistence of trifluralin by increasing retention of the herbicide and that the increased adsorptive capacity of the organic material probably is instrumental in retaining trifluralin vapors. Since they believed that trifluralin dissipated as a vapor, they felt that the addition of organic matter colloids retains more of the vapor in the soil and thus increases toxicity. Eshel and Warren (1967) reported that the organic matter content of the soil appeared to be the most consistent factor affecting herbicide persistence because of its high capacity to inactivate herbicides in the soil. They also found much greater activity of chloramben and trifluralin in fine soil with little organic matter compared with a high organic matter soil. Linscott et al. (1969) and Schliebe et al. (1965) reported that the adsorption of radioactive chloramben was closely associated with level of organic matter in soil.

Soil Type. Herbicidal activity is strongly influenced by soil type. Soil type is dependent upon the % of sand, silt, and clay, but the most important component is the quantity and type of clay mineral. Organic matter is not considered a component of soil type; however, organic matter contents are frequently used within a soil type to better define or determine the proper herbicide rate. Eshel and Warren (1967) and Rauser and Switzer (1962) reported that the phytotoxicity of chloramben was much less in a high organic soil than in silt loam and fine sands. Linscott et al. (1969) reported more adsorption of chloramben in soils containing an illite clay than in soils containing other types of clay. Schliebe et al. (1965) also studied 4 clays and found that kaolinite adsorbed chloramben most readily; however, they did not include an illite clay.

Dowler and Hauser (1969) reported more injury to soybeans from vernolate on a Tifton loamy sand than on a Greenville sandy clay loam. Depth of incorporation was more crucial in Tifton soil than in Greenville soil. Hauser et al. (1969) reported that several factors influenced the activity of vernolate on weeds in peanuts, but that soil type was particularly important. Their data suggested that the methods of placement were less critical on Greenville sandy clay loam than on the Tifton loamy sand. Peanuts on the Greenville soil were injured less by incorporated vernolate than peanuts growing on the Tifton

loamy sand. Trifluralin and chloramben caused considerably more injury in a fine sand than in a silt loam, and caused more injury in the silt loam than in a muck soil (Eshel and Warren 1967) (see Figure 4). Dowler and Hauser (1970) also found more injury to soybeans with trifluralin and benefin on Tifton loamy soil than on Greenville sandy clay loam. Dowler et al. (1958) reported that on light soils, movement of dinoseb seems as much a function of soil type and pH as it is of the amount of rainfall applied. Activity of dinoseb tended to be greatest in the lower soil layers. Davis (1956) reported that dinoseb was less toxic on a silt loam soil than on a sandy loam soil. Results such as these give rise to the general recommendations that herbicide rates be reduced as the soils become more sandy and lower in organic matter.

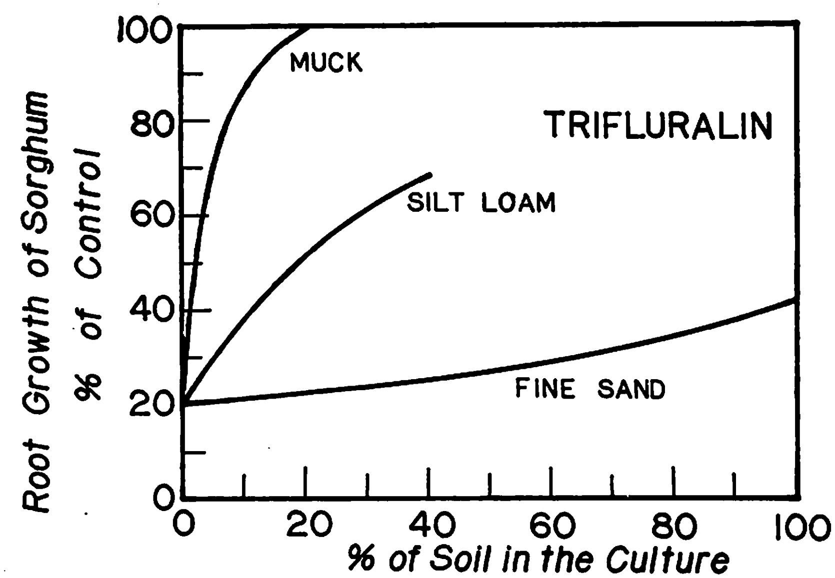

Fig. 4. Effect of relative amount of soil in seedling culture on inactivating trifluralin. Concentration of herbicide solution was 2 ppm (Adapted from Eshel and Warren, 1967).

Pesticide Interactions and Seed Quality

A herbicide placed in or on the soil may react not only with the soil, but also with other pesticides or agricultural chemicals. Early research on pesticide interactions in the soil concerned cotton. Recently, more research has been conducted in this area on peanuts.

Concern with regard to pesticide interactions by weed scientists would certainly focus on herbicides or herbicide combinations resulting in reduced peanut quality or yield. Coble (1975) evaluated the interaction of several major peanut herbicides for peanut growth retardation. These treatments included preplant incorporated and ground-cracking stage applications and combinations of herbicides applied by these methods. Peanut yields were not affected by any herbicide treatment *per se*, but yields were reduced where the degree of weed control was low. Hauser et al. (1977) reported that preplant incorporated treatments of benefin followed by ground-cracking stage application of alachlor plus naptalam and dinoseb significantly increased the yield of Florunner peanuts. Delaying treatment with the ground-cracking mixture for 10 days did not depress yields when averaged over all soils; however, substantial and consistent yield reductions occurred when the herbicide sequence terminated with 5 repeated applications of dinoseb. Late planted peanuts were generally more susceptible to intensive herbicide treatments than the early plantings. Rud (1973) reported that sequential postemergence applications of dinoseb alone produced less injury to peanuts and less yield reduction than did combinations of dinoseb with other herbicides. Reduced peanut yields occurred with 4 sequential applications of the highest rate of dinoseb, 3 treatments of dinoseb plus alachlor, and 2 applications of dinoseb plus diphenamid and dinoseb plus naptalam.

Hauser et al. (1976) reported very few cases where a yield reduction was caused by pesticide-cultivar interaction from their extensive field experiments involving peanut cultivars, herbicide sequences, and a systemic insecticide. Yield increases were reported more frequently than yield reductions where multiple pesticides were used. One exception to this was the multiple application of dinoseb which did result in yield reductions in 2 of 8 experiments. In general, genetic and environmental factors influenced organoleptic quality and the fatty acid composition of peanut oil much more than did the herbicide or insecticide treatments. Hauser et al. (1977) showed that beginning intensive sequential treatments with vernolate reduced yields more than when benefin initiated the sequence. Average yields of Florunner peanuts were increased significantly by the insecticide disulfoton in most studies. The disulfoton X herbicide interaction was not significant.

Cargill and Santelmann (1971 a,b) in field studies, showed that disulfoton, phorate, dibromochloropropane, and pentachloronitrobenzene (PCNB) had little influence on chloramben and trifluralin phytotoxicity to peanuts. There was no phytotoxic effect or yield reduction reported from the application of chloramben or trifluralin with fungicide treated seed planted in the field. Walker et al. (1976) reported that the combination of a nematicide DBCP (1,2-dibromo-3-chloropropane), vernolate, benefin, and the inoculant of rhizobium sp. had no significant effect on yield or on sound mature kernels. The N content of the leaf and seed and the number of nodules were not affected by the treatments.

The field study of Chappell and Miller (1956) evaluating peanut disease and nematode intensity with herbicide treated peanuts indicated that herbicide usage may decrease disease development in peanuts; however, it was not actually known whether these herbicides were acting as fungicides and nematicides. It was believed that the covering of the crown and lateral branches with soil to control weeds may be especially important in aiding the development of certain diseases, and that chemical weed control may indirectly help control these diseases by making the early cultivations unnecessary. Garren and Duke (1957) reported that stem rot of peanuts was less and peanut yield greater with the "non-dirting" weed control with dinoseb than with the "dirting" cultivations. Additional results suggested that dinoseb may have some beneficial effects independent of whether soil is thrown onto the peanut plants. Backman et al. (1977) reported that oxadiazon and dinoseb significantly reduced the incidence of stem rot caused by the soil-borne pathogen *Sclerotium rolfsii* L. in field-grown peanuts. In laboratory tests, dinoseb was shown to be toxic to the pathogen while oxadiazon was non-toxic. Disease control with oxadiazon was thought to be indirect, perhaps relating to the reduced plant spreading observed in treated plots.

Johnson et al. (1975) studied the influence of herbicides, mono-cropping and multi-cropping sequences on population densities of nematode species common in corn, cotton, peanut, and soybean fields. The application of herbicides did not significantly affect nematode population densities. The peanut sequence, which included the herbicides benefin, 2,4-DB, vernolate, and 2,3,5-trichloro-4-pyridinol, was the most effective monocrop system for suppressing most nematode species.

Combining pesticides or herbicides with fertilizer solutions is frequently attempted in order to reduce the number of separate trips across a field to perform necessary production practices. Information on the multitude of possible combinations of agricultural products is very limited. Meyer et al. (1973) compared the chemical compatibility of a suspension fertilizer (containing 15% N, 6.5% P, and 12.5% K) with 5 different herbicides (butylate, alachlor, trifluralin, norea, and atrazine). All combined materials were both physically and chemically compatible and all herbicides were as effective when applied in combination with the fertilizer as when applied separately. All herbicides studied can be mixed with the suspension fertilizer prior to application and remain effective during the growing season, but agitation is required during storage.

Research with peanuts and other crops, particularly cotton, indicated that the quality of the seed used in planting the crop may influence injury from a herbicide. Boyle and Hauser (1962) suggested that poor emergence of herbicidally treated peanuts may be due in part to seed of poor vitality. Their greenhouse data showed that sesone did not depress emergence of peanut seed but seedlings from poor seed did not emerge satisfactorily.

Helmer et al. (1969) reported that although the emergence, growth, and yield of peanuts were directly related to seed quality, no interactions existed between trifluralin and seed quality. In contrast, Cargill and Santelmann (1971) conducted experiments using various procedures to reduce seed quality in order to determine if peanut seed quality influences the susceptibility of young peanut seedlings to trifluralin and chloramben injury. Seedlings from seeds without a seedcoat, or from one-half a seed with and without a seedcoat, were also more susceptible to herbicide injury than seedlings from visually sound seed. Injury to the germ end of peanut seed resulted in greater susceptibility of herbicide injury to the seedlings. The Dixie Spanish variety was slightly more susceptible to herbicide injury than Starr, Argentine, Spantex, Early Runner, or Virginia Bunch.

Santelmann (1972) showed in greenhouse experiments that peanut seed size was a factor affecting herbicide injury to peanut seedlings. More top and root injury occurred when using small seed in trifluralin treated soil than when medium, regular, or large seed were planted. There was little difference in root injury between the various seed sizes when chloramben was used. In field experiments, as size increased, top growth increased with all treatments. There were no yield differences with any of the seed sizes planted in soil treated with normal rates of trifluralin or chloramben.

Farmers will obtain the best results by planting only seed of high quality.

Vigorous seedlings resist unfavorable environmental factors, which may occur singly or in combination, better than seedlings of poor vitality. For example, potential stress from herbicides alone may be innocuous, but if combined with such other potentially detrimental influences as bad weather, seedling diseases and poor seedling growth, 2 or more of these factors may interact to drastically and adversely affect the peanuts. Therefore, high-vitality seed form an essential component of a well-executed weed control program.

Systems Approach to Peanut Weed Control

Weeds are a major factor to be reckoned with in the production of peanuts. Because of the extreme diversity in weed pests growing in peanuts and the highly adaptive nature of those weed species, successful suppression is almost invariably associated with some form of a systems approach. To rely on a single method, or herbicide, for weed control will usually ensure failure.

Steps in the Systems Approach

Analysis of the Soil and Associated Environmental Parameters. Peanuts are grown on a range of soils with many widely different properties. It is highly important to have a thorough understanding of such soil properties as soil texture, structure, organic matter, and cation exchange capacity. Certain factors affect herbicidal efficacy as well as determine the nature of the weed flora present in any given area. In addition to these soil characteristics, drainage and topography can influence weed management.

For an effective weed management program, each field or cultural unit should be identified and characterized with regard to soil and environmental parameters. Afterwards, appropriate consideration can be given to various weed management techniques.

Analysis of Weed Flora. The nature of the weed flora in peanuts varies with region and even within fields. Such variation can be accounted for because of differences in soil and environmental parameters as well as points of introduction of particular reproductive organs.

Many production factors such as fertility, soil pH, moisture, and herbicides affect the nature of the weeds found in peanuts. An important preliminary step in effective weed management is to identify the weed species present in a given area or field. Correct identification as well as knowledge regarding relative population density of weeds enables the judicious implementation of appropriate control measures. Because many control measures are used *a priori*, analysis of the weed flora often must be accomplished long before a crop is planted. Consequently, permanent records should be maintained for each field or production unit.

Awareness of the Effect of Cultural Practices on Weed Control. Because certain weeds quickly fill ecological niches in the crop environment, almost every cultural measure used in the production of peanuts sometimes influences weeds and their control. Such factors as crop rotation, land preparation, crop tillage, planting patterns, fertilization, seeding rate, crop variety, insects, diseases, nematodes, and irrigation can be manipulated to affect weed control. The consideration is to judiciously utilize such parameters to mitigate

the effect of weeds. While the merits of row-spacing, land tillage, and fertility and their effects on weed populations and growth are well known, much less is known regarding other factors such as crop rotation, seeding rates, and crop varieties.

Knowledge Regarding Efficacy of Specific Weed Control Measures. Having a firm grasp and full understanding of all relevant means of controlling weeds enables the grower to effectively deal with his weed problems. To be sure, most growers have an understanding of all available weed control measures, but often in a rather superficial way. Keeping abreast of new developments in herbicides and application technology is often a difficult assignment. The simple act of matching the most effective control procedure with the weeds to be controlled requires considerable skill. The added dimension of economics makes the situation even more of a challenge.

Rationale for the Systems Approach

Few would argue that the systems approach to weed control in peanuts is new. Indeed, the systems approach is almost as old as civilized agriculture itself. However, the utilization of all available control measures in harmonious concert with correctly identified problems is a relatively new concept. Such a process permits careful analysis of the problem and specific steps to achieve the desired results before committing any resources. Another step, which is becoming relevant with increasing costs of production, is a more careful consideration of economic parameters. The question changes from, "How to control a specific weed?" to other questions more relevant such as, "Does the weed need to be controlled?", "When can it be controlled more effectively?", "What herbicide is most cost-effective in controlling the weed?", "Can cultural methods be employed?"

Specific Examples of Weed Control Systems

While few would argue that there is one *best* system for controlling weeds in peanuts, there is a general consensus of agreement regarding basic control systems with given weed populations. Indeed, for certain particularly difficult to control species, the matter is even more clear-cut with regard to accepted procedures for control. The matter is somewhat complicated because many of the control systems are not completely effective in eliminating the weed problem.

SUMMARY AND OUTLOOK

Weed populations are not static but are constantly changing — sometimes subtly but often rapidly. Rapidly changing weed populations are challenging research scientists, extension workers, and farmers. Uncontrolled weeds encroach, shifting the weed patterns from easily controlled species to those controlled only with difficulty or not at all.

Before the era of mechanized farming, ecological shifts in weed populations usually were relatively slow. More recently, however, innovative mechanization, including widespread application of selective herbicides, induced accelerated and often dramatic ecological changes within cultivated fields. For example, during the 1940's, in the Georgia-Florida-Alabama peanut belt, the predominating weeds in many fields were crabgrass and Florida pusley. Farmers controlled these weeds with cultivation and hoeing. As the supply of labor decreased and as the demand for better and more precise weed control procedures increased, industrial and institutional research scientists developed herbicide practices which effectively controlled crabgrass and Florida pusley. Subsequently, in the 1950's, another weed, nutsedge (which previously was removed by hoeing) predominated in many peanut fields. About 1965, farmers began controlling nutsedge with a new selective herbicide. Later, in the 1970's, such broadleaf weeds as cocklebur, sicklepod, and Florida beggarweed, persisting in the environment for many years, emerged as very serious problems. These and other broadleaf weeds, although they usually emerge early in the season, often overtop the peanuts and become troublesome only after cultivation is no longer feasible. These uncontrolled broadleaf weeds interfere with harvesting operations and may also damage combines. Planting of high vitality seed in closely spaced rows (to encourage quick formation of a thick canopy of peanut leaves) will help suppress these troublesome weeds.

Similar ecological changes, involving these or other weeds, have occurred in other peanut producing areas. For example, in 1980, horsenettle (a very difficult-to-control perennial) was ranked as the most troublesome weed in Oklahoma. Such changes will undoubtedly continue to challenge the ingenuity of research scientists, extension personnel, and peanut producers.

An urgent need in peanut production, especially for the control of broadleaf weeds that cause trouble late in the season, is a low-toxicity short persistence herbicide that would selectively remove these weeds from peanuts using over-the-top postemergence applications. The growth habits of the peanut plant preclude application of herbicides as directed postemergence treatments. Low rates of 2,4-DB effectively suppress cocklebur and certain other weeds with acceptable crop tolerance. Unfortunately, this herbicide does not consistently suppress other broadleaf weeds such as Florida beggarweed.

Another major problem of the modern peanut farmer is integration of the effective cultural and chemical weed control methods into the most logical procedure for controlling his specific weeds. The term "prescription approach" implies tailoring control measures to specific weeds and environmental conditions. A closely related concept involves "systems of weed control". Such systems could involve as components: (a) herbicides only, (b) cultivation only, or (c) a number of logical combinations of both herbicides and cultivation. Timeliness of either the herbicide application or of cultivation may be critical in a weed control system. Follow-up sprays of dinoseb are most effective if applied as soon as the weeds are visible and are much less effective if delayed until weeds are larger. Under some conditions, only 1 timely cultivation contributes substantially to controlling late-season weeds where herbicides were applied previously. A very important component of the systems approach is row spacing. Close-rows usually produce more peanuts and tend to greatly decrease weed growth when compared to conventional spacings.

Another concept which undoubtedly will become more important in the future is "the herbicide-crop rotation" concept. It may be particularly applicable to peanuts since directed postemergence treatments with herbicides are precluded. The herbicide-crop rotation concept involves a total rotational approach emphasizing excellent control of weeds with the herbicides and cultural techniques, including row spacing, that are best suited to each crop. Weeds difficult to control in 1 crop may be easily controlled in another. For example, Florida beggarweed, hard to control in peanuts, is relatively easy to control in corn or cotton. Over a period of years, controlling each weed at its most vulnerable spot in the rotation will reduce infestations considerably.

Integrated pest management is yet another concept with critical implications for the future of peanut production. The control of weeds and other major pests with the most effective and economical utilization of all production inputs is a goal which challenges scientists, extension specialists, and farmers.

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This is a report on the current status of research involving use of certain chemicals that require registration under the Federal Insecticide, Fungicide, and Rodenticide Act as amended. It does not contain recommendations for the use of such chemicals nor does it imply that the uses discussed have been registered. All uses of these chemicals must be registered by the appropriate State and Federal agencies before they can be recommended.

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