chemical or mechanical method to remove woody plants from rights-of-way will result in modification of floristic composition of the remaining plant community. Such modifications occur due to removal of the overstory plant cover, regardless of methods employed, either chemical or mechanical. Some plant species such as lady slipper may decline or disappear under right-of-way conditions while others expand and flourish. Resultant changes in plant composition may be beneficial to some organisms such as certain wildlife species. This is an obvious relationship that occurs under natural as well as man-induced changes in the environment.

Indirect effects of 2,4,5-T application to target plants could occur in the terrestrial and aquatic environment and may influence future management options. Such indirect effects, however, are primarily related to application methods, i.e. nonselective versus selective techniques.

Terrestrial Environment

Vegetation

The short-term direct effect of 2,4,5-T application is the immediate response of the treated vegetation, both desired and undesired, to the herbicide. In the short term, approximately 1 to 2 years, the treated vegetation either dies or recovers. For broadcast foliage applications there is a rapid "brown out." Treated plants exhibit certain growth abnormalities such as bending, twisting of new stems and abnormal leaf development, particularly when herbicide has been applied at lower rates. Often the treated vegetation simply wilts and dies. Selective application techniques have similar effects on treated vegetation but with minimal disturbance to nontreated plants.

In contrast, indirect effects on vegetation may be evident over a longer term and generally are expressed as plant community changes, i.e., adjustments in floristic composition. Some community components may be altered for a period of time and others entirely removed and replaced by different species. The magnitude of plant community changes due to 2,4,5-T treatment is related to application technique. Selective methods cause the least disturbance to nontreated vegetation and ultimate community composition except for removal of undesired target plants such as tree species on the rights-of-way. Even with severe plant community alterations resulting from nonselective application methods, the vegetation may return to the original composition over a period of 10 to 20 years (Bramble and Byrnes 1972, 1974).

Generally, after repeated broadcast application of 2,4,5-T, the remaining plant community is typified by the near absence of broadleaf herbaceous plants and many woody species. The plants remaining tend to be grasses, ferns, sedges, and other species resistant to the herbicide treatment (Carvell and Johnston 1978).

Where the material is repeatedly applied in a selective manner such as a basal stem treatment, the resultant plant communities are much more species diverse. There will be more abundance of shrubs and woody plants, as well as herbaceous species (Carvell and Johnston 1978; Bramble and Byrnes 1975).

Effects on Animals

In general, animals require a broad diversity of habitat types. Many wildlife species thrive in this transitional zone, ecotone, between diverse vegetation types. Bramble and Byrnes (1974) have shown that wildlife usage on the rights-of-way treated with 2,4,5-T was greater than on adjacent undisturbed forests. Depending on the degree of disturbance from 2,4,5-T treatment, wildlife habitat may be altered for a short period, then recover, similar to conditions following fires. Further, openings and low plant cover created by spraying may be more favorable to certain wildlife species such as turkey and quail, but less favorable for large mammals. A report on 22 rights-of-way in New York State has shown that wildlife use is diverse and common on rights-of-way where 2,4,5-T had been used (Asplundh Environmental Services, 1977).

Soil

The application of 2,4,5-T for vegetation control has a minimal effect on soil (Asplundh Environmental Services 1977). Because of rapid vegetation and the lack of site disturbance, there are minimal amounts of erosion and compaction. Because of the selective nature of 2,4,5-T to vegetation, and the lack of residual activity, large areas of exposed soil do not occur (Carvell and Johnston 1978). Erosion problems on such rights-of-way tend to occur only in situations where constant vehicular or pedestrian traffic and construction activities maintain exposed soil conditions (Asplundh Environmental Services 1977).

Aquatic Environment

The aquatic environment receives minimal impact from herbicide usage in rights-of-way situations. Rights-of-way generally occupy very small parts of watersheds for particular streams, and water exposure is generally limited to that short span where the water course crosses the right-of-way. The major influence of right-of-way management on streams would arise through the removal of protective stream bank vegetation on those limited sites. In this case there may be small increases in water temperature on warm summer days. However, these temperature increases are only on the order of 3°C which do not adversely affect fish (Carvell and Johnston 1978). Because of restrictions on the label regarding 2,4,5-T and its use around water, rights-of-way managers do not treat riparian vegetation. Research in forest applications where major portions of watersheds have been treated have indicated little occurrence of 2,4,5-T in downstream water (Norris 1967, Patric 1971). Since an even smaller portion of watersheds is treated in rights-of-way, it would appear that the occurrence of the herbicide in downstream water would be essentially zero. The removal of woody vegetation from streambanks can result in increased erosion since deep-rooted species are not present. Silting of the stream channel can be an undesirable consequence (Carvell and Johnston 1978).

CHEMICAL ALTERNATIVES

There is available to the right-of-way manager a variety of other herbicides for controlling vegetation. The nature of this list would depend on right-of-way objectives, particular situations and policies on the part of the industry, and characteristics related to each individual herbicide. Each herbicide has unique characteristics, causes different responses in individual species, and also has quite different ecologic impact on specific sites. While individual responses are important, the collective response of the species complex can be most important in assessing impacts and benefits of the use of any method.

One important criteria in the selection of any herbicide treatment is the degree of control of the many target species on any site or efficacy. Table 6 presents a relative comparison of the responses to 2,4,5-T with other established herbicides for hardwood and deciduous woody-plant species of particular importance in the Eastern Region and the Pacific Northwest. This information is compiled from Agricultural Handbook No. 493, Response of Selected Woody Plants in the United States to Herbicides (Bovey 1977).

Table 7 is a summary of the information in table 6 for deciduous woody species showing the relative responses to different herbicides applied as basal and foliar sprays. These numbers do not connotate satisfactory control, only the relative degree of response. It is readily apparent that 2,4,5-T is much more effective than 2,4-D, dichlorprop, or silvex when used at normal use rates. AMS is effective on more species than 2,4,5-T when applied as a ground foliar spray, but is also nonselective for grasses and other vegetation. Dicamba appears to be better than 2,4,5-T as a basal spray. Dicamba alone is less effective than 2,4,5-T (lb for lb) on oak, maple, sassafrass, locust, elm, gum, and sumac (Starke 1978). Dicamba activity is enhanced when used in combination with other herbicides. Picloram greatly exceeds the efficacy of 2,4,5-T either as a basal spray or foliar application, but may be more readily transported in runoff water and has some soil residual activity.

Table 6--Comparative responses to 2,4,5-T with other selected herbicides by hardwood and deciduous woody plant species and method of application[a/]

Species	2,4-D		AMS		Dicamba		Dichlorprop		Picloram		Silvex	
	BS	FS	BS	FS	BS	FS	BS	FS	BS	FS	BS	FS
Alder												
common	+	=	+	=	=	-	=	-	=	-	+	-
red	=	=	=	=	-	-	=	-	-	-	-	=
Ash												
green	+	+	-	-		+	+	+			+	+
white	+	+	-	-	-	-	+	+	-	-	+	+
Aspen, quaking	+	=	+	+	=	+	+	=	=	+		
Basswood	+	+	-	-		-		+		-		
Beech, American	=	+	=	-		-		=		-		
Birch	=	+	=	=		=		=		=		=
yellow	+	+	+	+		=		+		=		
Boxelder	=	=	-		=		=	+	=	=	=	
Buckeye	+	+	+	-		-	+	+				-
Catalpa	+	+	+	+		-		+		-		+
Cedar												
Eastern red	+	=	-	-	-	-	-	=	-	-		
Northern white	+	=	-	-		-	+	-		-		
Cherry	+	+	=	-	=	-	=	+	=	-		+
Chinkapin												
allegheny		+	+	+		=						
golden		=		+						=		
Coffeetree, Kentucky		+	+	-	-							
Cottonwood		+		=		+		+			+	=
plains	=	+		=		=	=	=		=		=
Dogwood	=	=	=	=		=				=		
Elm												
American	+	=	+	-	=	=	+	=	=	-	+	=
slippery red	+	=	+	=		=		-				=
winged	+	+	+	=	=	+	+	+	=	-	+	+

Continued.

Table 6--Comparative responses to 2,4,5-T with other selected herbicides by hardwood and deciduous woody plant species and method of application a/ (Continued)

Species	2,4-D		AMS		Dicamba		Dichlorprop		Picloram		Silvex	
	BS	FS	BS	FS	BS	FS	BS	FS	BS	FS	BS	FS
Fir, balsam	=	=	-	-						-		
Gum												
black	+	+	=	-	-	-	+	+	-	-	+	+
sweet	+		=	=		=	+	+	=	=	=	=
Hackberry	=	+	=	+		+	=	+		=	=	=
Hawthorn	=	-	=	-	=	=	-	=	-	-	=	=
Hemlock	-	=	-	-	-	-	-	-	-	-		=
Hickory	+	+	=	=	+	+	+	+	=	=	=	=
Honeylocust	+	+	+	+		+	+	+		=		+
Hophornbeam, Eastern	=	=	=	=		-		=		-		
Hornbeam, American	=	=	=	=						=		
Juniper	=	+	-	-	-	-	-	=	-	-	=	=
Larch	=	=	+	+								
Locust, black	=	=	+	+	-	-	+	=	-	-	=	=
Madrone, Pacific	=	=		+								
Magnolia												
cucumbertree	=	+	-	-								
sweetbay	=	+	+	=		+	-	+		-		+
Maple												
bigleaf		=									-	-
red	+	+	=	-	-	=	+	+	-	-		
silver	+	+	=	-						-		
sugar		+		-								
vine					+	+	+	+	=	-	=	+
Mulberry, red	+	+	=	+	-	-	+	+	-	-	-	-

Continued.

Table 6--Comparative responses to 2,4,5-T with other selected herbicides by hardwood and deciduous woody plant species and method of application a/ (Continued)

Species	2,4-D		AMS		Dicamba		Dichlorprop		Picloram		Silvex	
	BS	FS	BS	FS	BS	FS	BS	FS	BS	FS	BS	FS
Oak												
blackjack	+	+	=	–	=	+	+	+	=	+	=	=
black	+	+	=	=	=	=	+	+	=	=	=	=
blue	=	+	=			–	=	=	+		+	=
California black			+	+								=
chestnut	+	+	=	–	=	–	+	+	=	=		+
live	+	+	–	=	+	+		+		–		=
Northern red	+	=	=	–	=	–	+	=	=	–	+	–
pin	+	=	=	–		=	+	+	=	–	+	+
post	+	+	=	–	=	=	+	=	=	+	=	=
sand shinnery	+	+	+	+		+		+		=		–
scarlet	=	+	=	=	–	=	=	+	–	–	–	=
swamp	+	+	–	–								
white	+	+	=	–	=	+	+	+	=	=	+	+
Osage orange	+	+	+	+		+	+	+	+	+		=
Pecan	+	=	+	=				=				=
Persimmon	+	=	–	=	–	–	+	+	–	–	=	+
Pine	=	=	–	–	–	–	=	=	–	–	–	=
shortleaf		–								–		=
Plum, wild	+	–	=	=	=		+	=	=	–	=	=
Poison ivy	+	+	=	=		=		+		=		+
Poison oak	+	+	=	+			+			=		=
Pacific			+	+					=	–		–
Poplar, balsam	–	=	–	–					–	–		–
Prickly-ash	+	=	–	–		=		=		=		=
Red bud	+	+	+	–	–	–	+	+	–	–		=
Rose		+		+				+				+
Saltcedar	=	=	=		+	–	+	=	=		+	=
Sassafras	=	=	=	=	–	+	+	+	–	–	–	+
Sourwood	+	+	+	+	=	+	+	+	=	–		+

Continued.

Table 6--Comparative responses to 2,4,5-T with other selected herbicides by hardwood and deciduous woody plant species and method of application a/ (Continued)

Species	2,4-D		AMS		Dicamba		Dichlorprop		Picloram		Silvex	
	BS	FS	BS	FS	BS	FS	BS	FS	BS	FS	BS	FS
Spruce	+	=	+	+		=		+		-		+
Sumac	+	=	+	+	=	=	-	=	=	=		=
Sycamore, American	+	+	+	=	=	-	=	+	=	-	=	=
Tree-of-Heaven	+	=	+	+	=	=	+	=	=	=		+
Walnut	=	=	=	=		=		=		=		=
Willow	=	-	=	=	=						=	=
black	=	=	=	=		+		=		=		=

a/ BS-basal spray; FS-foliar spray; "+" - 2,4,5-T more effective than that herbicide applied in this manner; "=" - 2,4,5-T as effective as that herbicide applied in this manner; "-" - 2,4,5-T less effective than that herbicide applied in this manner.

Table 7--*Comparative responses to 2,4,5-T with other herbicides on deciduous woody species*[a/]

2,4,5-T effect	Basal spray	Foliar spray
	(number of species)	(number of species)
> 2,4-D	42	41
= 2,4-D	21	24
< 2,4-D	1	3
> AMS	22	19
= AMS	32	25
< AMS	11	24
> dicamba	4	17
= dicamba	19	19
< dicamba	10	19
> dichlorprop	30	35
= dichlorprop	9	19
< dichlorprop	3	3
> picloram	2	4
= picloram	23	22
< picloram	12	31
> silvex	13	20
= silvex	14	35
< silvex	5	8

a/ Deciduous woody species summarized from table 6 (hardwood species not included).

When looking at spectrums of plant control, it should be recognized that there is a continuous gradation of species in plant communities. Furthermore, there exists a gradation of response of a given species within a specific treatment. All members of a given species may not be controlled by a given herbicide even though the species may be considered "susceptible" to that treatment.

Use of non-2,4,5-T herbicide alternatives will result in lesser degrees of control, as illustrated in table 7. Consequently, the treatment cycle will generally be reduced from a four year average to three years. The most reasonable alternative herbicides and rates of application are described in more detail in the discussion of the economic impact of 2,4,5-T cancellation. These choices are based on many collective years of field experience by Asplundh Tree Expert Company, Chemical Department personnel.

There are many reasons why 2,4,5-T holds such a dominant position over other alternative herbicides in right-of-way usage. These reasons generally involve economics, efficacy, selectivity, and use familiarity. Current use patterns have grown out of extensive experience over the last 30 years. Some of the alternative herbicides are used in combination with 2,4,5-T to capitalize on advantages of each herbicide. Dicamba and picloram are both more expensive than 2,4,5-T and are more persistent in the environment. Consequently, neither is important as a treatment application alone. Combining these herbicides with 2,4,5-T reduces total herbicide cost, enhances control of many species as well as increasing the spectrum of susceptible species (particularly coniferous species), and reduces environmental residues. Picloram and dicamba may pose more hazard to adjacent sites than 2,4,5-T since these water-soluble herbicides may be more likely to be carried in runoff water. Trees growing adjacent to the right-of-way can be readily killed by absorption of herbicide from the treated soil. 2,4,5-T does not pose this problem. Dicamba alone is less effective than 2,4,5-T on many important and widespread woody plants that are weeds on rights-of-way including hickory, vine maple, blackjack and white oak, and sassafras (table 6).

Selectivity is a very important concept in rights-of-way management programs. The ballast area of railroad rights-of-way is the only major area where total vegetation control is the management objective. Selectivity is important for reasons of aesthetics and soil stabilization. Consequently, AMS is not a desirable alternative since it is a nonselective herbicide. In addition, AMS is highly corrosive to equipment, and high rates (60 lb/100 gallons water per acre) are necessary for brush control. Herbicides such as bromacil, tebuthiuron, hexazinone and glyphosate are nonselective herbicides and are not considered as 2,4,5-T alternatives of major importance. In addition, bromacil, tebuthiuron, and hexazinone are soil sterilant in nature which further reduces their potential viability as 2,4,5-T alternatives.

Glyphosate is a relatively untried herbicide for woody plant control in eastern U.S. Although it is essentially nonselective in terms of plant response it does not have residual soil activity. Its cost, currently around $60 for a 4-pound gallon, suggests that future use would likely be in combination with other herbicides such as 2,4,5-T. Glyphosate is most effective when applied late in the growing season.

Fosamine ammonium is currently being used in some locales for woody plant control. However, it must be applied late in the growing season before leaf coloration. Consequently, its use is to extend the spraying season and will not serve as a replacement to 2,4,5-T. This also apparently applies to glyphosate. It would be physically impossible to treat all the necessary acres in such a short time period.

MECHANICAL AND HAND LABOR ALTERNATIVES

Mechanical methods such as mowing, shearing, and rolling choppers, are currently being used in rights-of-way management. In some places and some situations, mechanical methods can be less costly than chemical applications. It seems logical to assume that right-of-way managers are currently using these methods where most economical. The fact that 2,4,5-T is currently used at the level it is, demonstrates that mechanical methods have severe operational limitations on many rights-of-way situations. Conditions such as rocky terrain, erosive soils, steep slopes, and winter weather limit use of mechanical methods. Many acres currently being treated with 2,4,5-T are physically impossible to treat mechanically.

In November, 1973, the Construction and Maintenance Division, Office of Highway Operations, Federal Highway Administration, conducted a poll of division offices regarding use and costs of vegetation management programs (Tidd 1974). From the relatively few states reporting costs of mechanical methods, principally mowing, and manual, the average costs were $23/acre, and $294/acre were average hand labor costs. The average cost of 2,4,5-T treatment was $23/acre. The states also reported that 2,4,5-T was less disruptive to the right-of-way, reduced sprouting, less hazardous on steep terrain, and made it possible to control large brush which would be difficult to mow. Kudzu and poison ivy were especially highlighted as weeds whose control was not possible by mechanical and manual methods. The states indicated that problems with manual methods included high costs, resprouts more difficult to control, operator hazard, and greatly increased frequency of treatment, often annually.

A survey of all Rural Electric Cooperatives was conducted by the National Rural Electric Cooperative Association in September, 1977 regarding their vegetation-management programs for rights-of-way and sub-stations. Based on respondents reporting per acre costs for mechanical and manual methods, mechanical costs for these electric cooperatives averaged $183/acre and manual costs averaged $657/acre.

For both surveys, manual methods are several times more expensive per treatment. Manual treatments tend to be repeated on a one to two year cycle. The relative operator hazard of manual brush control compared with chemical treatments is dealt with in the accident section of Chapter 5. It is highly unlikely that the necessary work force could be obtained to treat the total acres currently treated with 2,4,5-T.

DO NOTHING

The "Do Nothing" concept has little role in rights-of-way maintenance. The nature of the land use demands that materials, goods, services, and people be able to move safely and reliably. Consequently, the integrity of the right-of-way system simply must be maintained and will be maintained at some cost. In this type of land usage the costs, including any increased costs necessitated by alternative treatment types, will be passed along to the consumer.

ECONOMIC EFFECTS OF THE LOSS OF 2,4,5-T FOR VEGETATIVE MANAGEMENT ON RIGHTS-OF-WAY

ASSUMPTIONS

Certain assumptions were necessary in order to derive costs of vegetation management with and without 2,4,5-T. These assumptions were based on information from the Asplundh Tree Expert Company, the largest custom applicator of rights-of-way.

1. All acres currently treated with 2,4,5-T (alone or in mixture) will be treated with an alternative herbicide for vegetation management.

2. Average per-acre costs of selective treatment (both foliar and basal) and of stump spray after cutting are the same for all types of rights-of-way using these methods.

3. Only selective herbicides would be chosen in an alternative vegetation-management program because of the need to leave some vegetation for erosion control on rights-of-way. Aesthetics and wildlife management are also factors that limit the use of nonselective herbicides.

4. The level of control using any alternative will need to be the same as what is achieved currently using 2,4,5-T in order to maintain the integrity of the system supported by the right-of-way.

5. Currently, acres treated with 2,4,5-T once every four years would need treatment every three years, on the average, with the alternative herbicides to maintain the right-of-way system.

6. Cost figures and estimates of alternative choices provided by Asplundh Tree Expert Company are typical for all right-of-way areas under vegetation management currently using 2,4,5-T.

Results

The herbicide material cost per acre for 2,4,5-T treatment varies by type of application and right-of-way (ROW) (table 8). Because equipment used for broadcast foliar ground applications differs by ROW user, costs for this application method are presented by ROW type. The material cost per acre for 2,4,5-T varies from a low of $6.33 for broadcast foliar ground application used on highway ROW (primarily for herbaceous weed control rather than brush control) to a high of about $90 per acre for selective basal treatments and aerial applications. Material costs for other methods of application range from $35 to $50 per acre.

The alternative herbicides expected to be used if 2,4,5-T is canceled include Tordon 101, Banvel 4WS + 2,4-D, Weedone 170 and Banvel 520 (table 9). Herbicide material costs for the alternatives range from $7.69 per acre for broadcast foliar ground applications for highway ROW to about $85 for selective basal treatments and aerial applications. In general, the per acre costs for 2,4,5-T and the alternatives do not differ substantially. However, the alternatives are believed to be less efficacious.

The application cost varies from $107 per acre for aerial application for all ROW types to a low of $25 per acre for broadcast ground applications by highway ROW users (table 10). The application cost per acre is influenced by the type of equipment used, volume of spray applied, and whether the application is broadcast or selective. The high

Table 8--Herbicide treatment cost per acre for 2,4,5-T and 2,4,5-T vegetation-management program mixtures by type of treatment and right-of-way

Type of treatment	Herbicide[a]	Rate per 100 gals. of spray	Herbicide cost: Per gal. of product	Herbicide cost: Per 100 gal. of spray	Estimated use pattern	Weighted average cost per 100 gals	Quantity of spray per acre	Weighted average cost per acre
		Gals.	------Dollars------		Percent	Dols.	Gals.	Dols.
Ground								
Broadcast foliar:								
Highway	2,4,5-T	1.0	19.95	19.95	15			
	2,4,5-T+2,4-D	1.0	15.10	15.10	85	15.83	40[b]	6.3
Electric	2,4,5-T	1.0	19.95	19.95	30			
	2,4,5-T+2,4-D	1.0	15.10	15.10	40			
	2,4,5-T+Tordon 101	0.5+0.5	9.98+10.61	20.59	15			
	Banvel 710	1.0	18.20	18.20	15	17.84	300	53.52
Railroad	2,4,5-T	2.0[c]	19.95[c]	39.90	15			
	2,4,5-T+2,4-D	2.5[c]	15.10[c]	37.75	85	38.07[c]	25	
	2,4,5-T	1.0	19.95	19.95	15			
	2,4,5-T+2,4-D	1.0	15.10	15.10	85	15.83	300	41.84[d]
Selective:								
Foliar	2,4,5-T	1.0	19.95	19.95	30			
	2,4,5-T+2,4-D	1.0	15.10	15.10	40			
	2,4,5-T+Tordon 101	0.5+0.5	20.59	20.59	15			
	Banvel 710	1.0	18.20	18.20	15	17.84	200	35.68
Basal	2,4,5-T	3.5	19.95	69.83	20			
	Tordon 155	1.0	55.60	55.60	50			
	2,4,5-T+2,4-D	4.0	15.10	60.40	30	59.89	80	87.91[e]
Stump spray	2,4,5-T	3.5	19.95	69.83	20			
after	Tordon 155	1.0	55.60	55.60	50			
cutting	2,4,5-T+2,4-D	4.0	15.10	60.40	30	59.89	45	49.45[f]
Aerial								
Broadcast foliar:	2,4,5-T +	2.0+2.5[g]	92.95	92.95	70			
	Tordon 101	1.5+2.0[g]	72.36	72.36	30	86.77	[f]	86.77

continued

Table 8--Herbicide treatment cost per acre for 2,4,5-T and 2,4,5-T vegetation-management program mixtures by type of treatment and right-of-way (continued)

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a/ Assume 4 lb/gal ae for 2,4,5-T alone or 2 lb/gal ae each for 2,4-D and 2,4,5-T combinations.

b/ Rate for herbaceous weed control rather than brush control.

c/ Based on rate of product in 25 gallons of water.

d/ Assumes that 60 percent of the use will be at 25 gallons per acre.

e/ Includes cost of 80 gallons of oil at $.50 per gallon.

f/ Includes cost of 45 gallons of oil at $.50 per gallon.

g/ Based on a combination of the rate of herbicide in 25 gallons, of water, 25 gallons of spray per acre, and rate of herbicde in 15 gallons of water, 15 gallons of spray per acre.

SOURCE: David Fritsch, Chemical Department, Asplundh Tree Expert Company, Willow Grove, Pennsylvania. Telephone Conversations with Harvey A. Holt, December 12-13, 1978.

Table 9--Herbicide costs per acre for alternatives vegetation-management program, if 2,4,5-T becomes unavailable, by type of treatment and right-of-way

Type of treatment	Herbicide	Rate per 100 gals. of spray	Herbicide cost: Per gal. of product	Herbicide cost: Per 100 gal. of spray	Estimated use pattern	Weighted average cost per 100 gals	Quantity of spray per acre	Weighted average cost per acre
		Gals.	Dollars	Dollars	Percent	Dols.	Gals.	Dols.
Ground								
Broadcast foliar:								
Highway	Tordon 101	1.0	21.22	21.22	70			
	Banvel 4WS+2,4-D	0.25+0.05	35.15+8.87	13.22	25			
	Weedone 170	1.5	14.25	21.38	5	19.23	40a/	7.69
Electric	Tordon 101	1.0	21.22	21.22	80			
	Banvel 4WS+2,4-D	0.25+0.5	35.15+8.87	13.22	15			
	Weedone 170	1.5	14.25	21.38	5	20.03	300	60.09
Railroad	Tordon 101	3.0b/	21.22	63.66	100	63.66b/	25	
	Tordon 101	1.0	21.22	21.22	70			
	Banvel 4WS+2,4-D	0.25+0.5	35.15+8.87	13.22	25			
	Weedone 170	1.5	14.25	21.38	5	19.23	300	61.26c/
Selective Foliar:	Tordon 101	1.0	21.22	21.22	80			
	Banvel 4WS+2,4-D	0.25+0.5	35.15+8.87	13.22	15			
	Weedone 170	1.5	14.25	21.38	5	20.03	200	40.06
Basal	Weedone 170	4.0	14.25	57.00	80			
	Banvel 520	3.0	17.85	53.55	20	56.31	80	85.05d/
Stump spray	Weedone 170	4.0	14.25	57.00	80			
	Banvel 520	3.0	17.85	53.55	20	56.31	45	47.84e/
Aerial	Tordon 101 +	2.5+	21.22	84.01				
	Weedone 2,4-DP	2.0	15.48		85			
	Tordon 101 +	2.5+	21.22					
	Banvel 4WS	1.0	35.15	88.20	15	85.27	f/	85.27

a/ Rate for herbaceous weed control rather than brush control.

b/ Based on rate of product in 25 gallons of water.

c/ Assumes that 60 percent of the use will be at 25 gallons per acre.

d/ Includes cost of 80 gallons of oil at $.50 per gallon.

e/ Includes cost of 45 gallons of oil at $.50 per gallon.

f/ Based on Tordon 101 + Weedone 2,4-DP used at 25 gallons of spray per acre and Tordon 101 + Banvel 4WS used at 15 gallons of spray per acre.

SOURCE: David Fritsch, Chemical Department, Asplundh Tree Expert Company, Willow Grove, Pennsylvania. Telephone Conversations with Harvey A. Holt, December 12-13, 1978.

Table 10--Average per acre costs of application for herbicide treatment by right-of-way type and method of application

Right of way	Method of application: Broadcast Air	Broadcast Ground	Selective Foliar	Selective Basal	Stump spray
	Dollars				
Highway	-	25	46	87	48
Electric	107	40	46	87	48
Railroad	107	20	-	87	48
Pipeline	107	-	46	-	-

SOURCE: David Fritsch, Chemical Department, Asplundh Tree Expert Company, Willow Grove, Pennsylvania. Telephone Conversations with Harvey A. Holt, December 12-13, 1978.

cost for aerial application is because helicopters are used rather than fixed-wing aircraft.

The annual treatment cost for the current 2,4,5-T vegetation-management program is estimated at $96.7 million for all rights-of-way (table 11). Electric utilities accounted for $78.4 million followed by railroads which accounted for $11.5 million. Selective basal treatments for all rights-of-way were estimated at $41.1 million followed by aerial treatments at $40.0 million. Annual treatment cost for the alternative vegetation-management program on the acres currently treated with 2,4,5-T is estimated at $97.9 million--$1.2 million more than the 2,4,5-T management program (table 12).

Because the alternative herbicides are believed to provide a shorter period of control than 2,4,5-T, ROW users are expected to use a 3-year treatment cycle rather than the current 4-year treatment cycle with 2,4,5-T. It is estimated that for all rights-of-way about 228,000 additional acres would need to be treated annually if 2,4,5-T use is canceled (table 13). Electric utilities would need to treat 155,000 additional acres followed by railroads at 42,000 additional acres.

The total annual treatment costs (material plus application) on the additional acres treated because of a shift from a 4-year to 3-year treatment cycle is estimated at $32.6 million for all rights-of-way with electric utilities bearing $25.9 million of the cost (table 14). Selective basal and aerial treatment costs on the additional acreage are estimated at about $13 million each.

If 2,4,5-T use on all rights-of-way is canceled, use of alternative herbicides is expected to increase annual vegetation-management costs by $33.9 million (table 15). Electric utilities would have increased management costs of $25.2 million followed by railroads at $6.3 million. Annual vegetation-management costs are estimated to increase about $1.0 million for highway and pipeline ROW. For all rights-of-way, vegetation-management costs with alternatives would increase by 35 percent over the

Table 11—Total treatment costs from 2,4,5-T vegetation-management programs by method of application and type of right-of-way

Type of right-of-way	Unit	Method of application: Broadcast: Air	Broadcast: Ground	Selective: Foliar	Selective: Basal	Stump Spray	Treated annually with 2,4,5-T
Highway							
Acres[a/]	No.	0	58,447	5,614	733	3,373	68,167
Cost per acre[b/]	Dol.	-	31	82	175	97	
Total cost	$1,000	-	1,812	460	128	327	2,727
Electric							
Acres[a/]	No.	159,479	43,927	21,151	234,254	6,528	465,339
Cost per acre[b/]	Dol.	194	94	82	175	97	
Total cost	$1,000	30,939	4,129	1,734	40,994	633	78,429
Railroad							
Acres[a/]	No.	27,836	99,996	0	43	0	127,425
Cost per acre[b/]	Dol.	194	62	-	175	-	
Total cost	$1,000	5,313	6,200	-	8	-	11,521
Pipeline							
Acres[a/]	No.	19,391	0	2,635	0	0	22,026
Cost per acre[b/]	Dol.	194	-	82	-	-	
Total cost	$1,000	3,762	-	216	-	-	3,978
Total cost all rights-of-way	$1,000	40,014	12,141	2,410	41,130	960	96,655

a/ Table 5.

b/ Herbicide material cost from table 8 and application cost from table 10.

Table 12--Total treatment cost for alternative vegetation-management program, if 2,4,5-T becomes unavailable, by method of application and type of right-of-way

Type of right-of-way	Unit	Method of application: Broadcast: Air	Broadcast: Ground	Selective: Foliar	Selective: Basal	Stump Spray	Treated annually with 2,4,5-T or alternative[c/]
Highway							
Acres[a/]	No.	0	58,447	5,614	733	3,373	68,167
Cost per acre[b/]	Dol.	-	33	86	172	96	
Total cost	$1,000	-	1,929	483	126	324	2,862
Electric							
Acres[a/]	No.	159,479	43,927	21,151	234,254	6,528	465,339
Cost per acre[b/]	Dol.	192	100	86	172	96	
Total cost	$1,000	30,620	4,393	1,819	40,292	627	77,751
Railroad							
Acres[a/]	No.	27,386	99,996	0	43	0	127,425
Cost per acre[b/]	Dol.	192	81	-	172	-	
Total cost	$1,000	5,258	8,100	-	7	-	13,365
Pipeline							
Acres[a/]	No.	19,391	0	2,635	0	0	22,026
Cost per acre[b/]	Dol.	192	-	86	-	-	
Total cost	$1,000	3,723	-	227	-	-	3,950
Total cost all rights-of-way	$1,000	39,601	14,422	2,529	40,425	951	97,928

a/ Table 5.

b/ Herbicide material cost from table 9 and application cost from table 10.

c/ Acres currently treated with 2,4,5-T will be treated with alternative program, if 2,4,5-T becomes unavailable.

Table 13--Comparison of acres treated annually--four-year cycle and three-year cycle

Row type	Total acres treated[a/]	Acres treated annually Four-year cycle	Acres treated annually Three-year cycle[b/]	Added acres to be treated annually[c/]
Highway	272,668	68,167	90,889	22,722
Electric	1,861,356	465,339	620,452	155,113
Railroad	509,700	127,425	169,900	42,475
Pipeline	88,104	22,026	29,368	7,342
Total, all ROW	2,731,828	682,957	910,609	227,652

a/ Derived from number of acres reported treated annually (table 5), every four years (e.g., 68,167 x 4).

b/ Total acres treated divided by 3.

c/ Difference between acres treated annually in a four-year cycle and in a three-year cycle.

Table 14—Additional acres treated annually because of a shift from a 4-year to a 3-year treatment cycle and total treatment costs, by right-of-way application method and total

Type of right-of-way	Unit	Method of application: Broadcast: Air	Broadcast: Ground	Selective: Foliar	Selective: Basal	Stump Spray	Added acres needing treatment annually
Highways							
Acres	No.	0	19,482	1,872	244	1,124	22,722
Cost per acre	Dol.	-	33	86	172	96	
Total cost	$1,000	-	643	161	42	108	954
Electric							
Acres	No.	53,160	14,642	7,050	78,085	2,176	155,113
Cost per acre	Dol.	192	100	86	172	96	
Total cost	$1,000	10,207	1,464	606	13,431	209	25,917
Railroad							
Acres	No.	9,129	33,332	0	14	0	42,475
Cost per acre	Dol.	192	81	-	172	-	
Total cost	$1,000	1,753	2,700	-	2	-	4,455
Pipeline							
Acres	No.	6,464	0	878	0	0	7,342
Cost per acre	Dol.	194	-	86	-	-	
Total cost	$1,000	1,241	-	76	-	-	1,317
Total cost all rights-of-way	$1,000	13,201	4,807	843	13,475	317	32,643

a/ Table 13, distribution of acreage by method of application estimated by assessment team.

b/ Herbicide material cost from table 9 and application cost from table 10.

SOURCE: David Fritsch, Chemical Department, Asplundh Tree Expert Company, Willow Grove, Pennsylvania, Telephone conversations with Harvey A. Holt, December 12-13, 1978.

Table 15--Estimated increase in annual vegetation-management program costs on rights-of-way, if 2,4,5-T becomes unavailable

Type of right-of-way	2,4,5-T treatment costs[a]	Alternative treatment costs			Increased cost of alternative treatment[d]	Increase in treatment cost
		On acres currently treated with 2,4,5-T[b]	On additional acres treated annually[c]	Total		
	---Thousands of Dollars---					--Percent--
Highways	2,727	2,862	954	3,816	1,089	40
Electric	78,429	77,751	25,917	103,668	25,239	32
Railroad	11,521	13,365	4,455	17,820	6,299	55
Pipeline	3,978	3,950	1,317	5,267	1,289	32
Total	96,655	97,928	32,643	130,576	33,916	35

a/ From table 11.

b/ From table 12.

c/ From table 14.

d/ Total alternative treatment cost minus 2,4,5-T treatment cost.

current 2,4,5-T vegetation-management program, ranging from a high of 55 percent for railroads to a low of 32 percent for electric and pipeline ROW. [1/]

Limitations

Certain problem areas and limitations became evident during this analysis. Included are the following:

1. The lack of a historical data base on the use of 2,4,5-T and other herbicides on rights-of-way limited the comprehensiveness of this analysis and the estimation of the complete impact of using alternative herbicides. Without historical data much of the analysis is based on limited surveys and professional judgment.

2. Some species of woody plants are not controlled by an alternative herbicide (table 7) (Bovey 1977). Added use of manual methods may be necessary to maintain current level of control. Use of manual methods on certain woody species intensifies management problems because of sprouting which rapidly increases density of manually cut plants.

[1/] The rights-of-way survey by Asplundh Environmental Services discussed in a previous section also addressed the question of economic benefits of 2,4,5-T use and non-use. Rights-of-way managers, overall, estimated their cost increase to be 42 percent of current expenditures if 2,4,5-T were not available and all currently registered herbicides were available. Rights-of-way contractors, given the same conditions, estimated, on the average, that alternative methods would increase costs 46 percent over current expenditures (Asplundh Environmental Services, 1978). Similarly, Senechal and Besley (1975) reported that if 2,4,5-T were restricted for rights-of-way use, and all other phenoxy herbicides were available, costs would increase 42 percent the first year and 65 percent as the treatment cycle was shortened.

3. Length of time in a treatment cycle varies by geographic region. Currently, a 3-year cycle is needed in the Southeast and a 5-year cycle in the Northeast. Impacts in this analysis were derived using an average of four years for 2,4,5-T and an average of 3 years for the alternatives. Actual impacts in the Southeast may be higher per acre and those of the Northeast lower per acre than what was presented in this analysis.

4. Regional distribution of acres currently treated with 2,4,5-T could not be determined.

5. Prices for various herbicides included in the analysis imply specific quantity discounts to right-of-way owners. Individual rights-of-way owners, managers, and commercial applicators may pay more or less for their herbicides.

CHAPTER 4: THE BIOLOGIC AND ECONOMIC ASSESSMENT OF 2,4,5-T USE IN THE PRODUCTION OF RICE IN THE UNITED STATES

SUMMARY

Rice is grown on 2.5 million acres annually, located mainly in four southern states (Arkansas, Louisiana, Texas, and Mississippi) and California. Small acreages are also located in Missouri and several other southern states. Where rice is grown, the crop is intensively managed and contributes significantly to the rural economy.

The broadleaf-aquatic weed complex in rice in the lower Mississippi Valley is controlled by 2,4,5-T. The principal problem weeds that are effectively controlled by 2,4,5-T in the Arkansas, Mississippi, northern Louisiana, and Missouri rice-producing areas are hemp sesbania, northern jointvetch, morningglory, ducksalad, and redstem. Presently, 2,4,5-T is applied annually to 292,000 acres of rice by aircraft and to 8,000 acres of rice levees by ground sprayers--a total of 300,000 acres in the 4-state area; 28 percent of the 1,080,000 total acres in this 4-state 2,4,5-T use area is treated each year. Since the most common use rate is 1 lb/A acid equivalent, 300,000 pounds of 2,4,5-T are applied annually to rice in the U.S., all in the Mississippi Valley.

Although alternate herbicide treatments control the broadleaf-aquatic weed complex less effectively than 2,4,5-T, the first choice herbicide substitutes would be the combination use of (1) silvex, 2,4-D, and propanil, and (2) propanil and 2,4-D. Either of these combinations could be substituted for 2,4,5-T on all of the 300,000 acres presently treated with 2,4,5-T. The pattern of use for the first combination would be applications of silvex and 2,4-D where they could be applied safely from standpoints of rice and nontarget crops, such as cotton and soybeans; propanil would be used on the remainder of the 2,4,5-T treated acreage. The pattern of use for the second combination would be applications of 2,4-D where it could be used safely from standpoints of

rice and nontarget crops, mainly cotton; propanil would be employed on the balance of the 2,4,5-T treated acreage.

Silvex controls the broadleaf-aquatic weed complex almost as effectively as 2,4,5-T; acreage treated with this herbicide would not encounter losses from increased weed infestations. However, 2,4-D and propanil do not control the weed complex as effectively as 2,4,5-T. Rice receiving these treatments would encounter losses from increased weed competition. 2,4-D controls hemp sesbania and morningglory as well as 2,4,5-T, but it fails to control northern jointvetch, ducksalad, and redstem as effectively as 2,4,5-T. Rice receiving propanil treatments would experience losses because it does not control northern jointvetch, ducksalad, morningglory, or redstem as effectively as 2,4,5-T; however, it controls hemp sesbania as well as 2,4,5-T.

MCPA, molinate, bifenox, bentazon, and oxadiazon, which are other herbicides registered for use in rice, do not control weeds as effectively as 2,4,5-T. They are not effective substitutes for 2,4,5-T in weed-control programs for rice. Cultural weed-control practices, such as seedbed preparation, seeding method, water management, summer fallowing land, and crop rotations are relatively ineffective for control of the broadleaf-aquatic weed complex susceptible to 2,4,5-T.

The lack of an effective herbicide such as 2,4,5-T for control of the broadleaf-aquatic weed complex in rice would lower production returns to rice growers. Based on average yield and quality losses for the 1975-77 period, returns to rice growers would be reduced $4.2 million annually during the first 3-year cropping cycle if 2,4,5-T were not available and the best alternate herbicide treatments (silvex, 2,4-D and propanil) were substituted for 2,4,5-T. During the second 3-year cropping cycle, rice growers would encounter even greater losses because weed infestations would increase; losses each year would be $6.7 million if the best alternate herbicide treatments were substituted for 2,4,5-T. If the second-best alternate treatments (propanil and 2,4-D) were substituted for 2,4,5-T, rice farmers would encounter losses of

$5.4 and $8.9 million annually during the first and second 3-year cropping cycles, respectively.

Total losses during the 6-year period after 2,4,5-T became unavailable would be $25.2 million if the best alternate treatments (silvex, 2,4-D and propanil) were substituted for 2,4,5-T. If 2,4,5-T and silvex are not available for use in weed-control programs, rice farmers would substitute propanil and 2,4-D, the second-best herbicide treatments, for 2,4,5-T. With this program the producers' loss would be a total of $33 million during the 6-year period immediately following unavailability of 2,4,5-T and silvex.

INTRODUCTION

Rice is the only agricultural commodity for human consumption in the United States which may be directly sprayed with 2,4,5-T during its production. This chapter describes weed-management practices and the use of 2,4,5-T for weed control in rice, use of alternative weed-control practices, estimates of present and potential use of 2,4,5-T for weed management in rice, and the potential impact of canceling the registration of 2,4,5-T on rice productivity and production costs.

This chapter is organized into three major parts:

The weed problem and available methods of control -- Assesses the overall losses caused by weeds in the U.S., identifies the specific weeds that are troublesome in rice, and describes weed control systems that are used by rice farmers.

Potential solutions for the problem -- Identifies herbicides and weed-control practices that are essential to an effective weed management system, emphasizes the importance of an integrated approach to weed management, and discusses new experimental approaches to weed control in rice.

Rice production and weed control -- Rice production management goals are defined as related to biology and ecology of plant communities in rice fields, weed impact on commodity yield and quality, and weed management strategies. Methods for controlling the weed problem in rice are discussed in depth; these include chemical alternates such as 2,4,5-T, propanil, 2,4-D, silvex, other herbicides, and combination uses; cultural-mechanical-hand labor alternates such as summer-fallowing, seedbed preparation, crop rotations, seeding methods, water management, cultivation, and handweeding; and a do-nothing approach. Each method subdivision includes patterns of use, efficacy, potential levels of use, changes in production costs, effects on yield and quality of the commodity, availability, direct and indirect effects on the environment which include influences on man, animals, vegetation, aquatic life, soil, water, atmosphere, and other aspects.

METHODOLOGY AND ASSUMPTIONS

The analysis of the economic implications of the use of 2,4,5-T to control weeds in rice assumes the following.

1. The analysis compared the economic effect of two scenarios; i.e., (1) availability of 2,4,5-T for use on rice versus unavailability of 2,4,5-T; (2) availability of 2,4,5-T for use on rice versus unavailability of 2,4,5-T and silvex.

2. The analysis was limited to the rice-growing areas of Arkansas, Mississippi, Louisiana, and Missouri (fig. 1) that need 2,4,5-T for effective weed management, which accounts for 11 percent of the 1975-77 average U.S. rice production. Rice-growing areas in California were not included because 2,4,5-T is seldom used for weed control. This is because cotton is not intercropped with rice and other materials can be used.

Other materials also provide adequate weed control in Texas.

3. The 1975-77 average acres, production, and value of rice were assumed to be representative of acres, production, and value of rice that would occur in the 1978-83 analysis period, if 2,4,5-T were unavailable. The 1978-83 analysis period was selected so as to include two cycles of rice-soybean rotations (one year rice and two years soybeans). It was assumed that this period was adequate to demonstrate the short-term to mid-term effects of weeds in rice without 2,4,5-T.

4. Partial budgets, considering only materials and cultural practices that changed, were used to estimate cost differences of 2,4,5-T and alternative weed-control programs. The partial budgets were developed by research and Agricultural Extension Service personnel in the respective production areas.

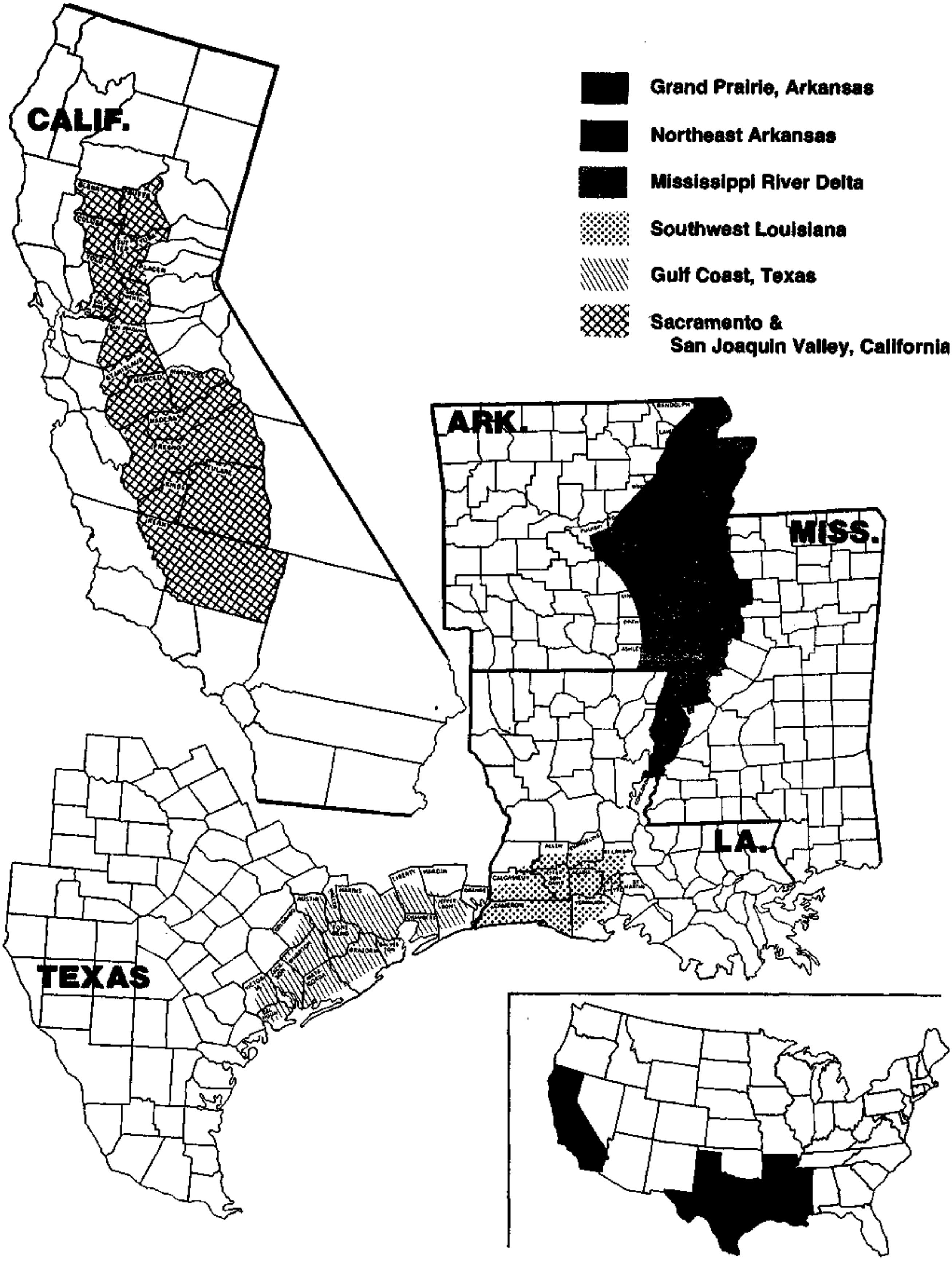

Figure 1. Major U.S. rice areas (Mullins et al. 1978).

5. Quality effects of weed-associated foreign matter and yield-reducing effects of weeds in rice were considered in estimating economic losses associated with the lack of 2,4,5-T.

6. The analysis assumes that no new herbicides that control the weed complex susceptible to 2,4,5-T, will be registered for use in controlling weeds in rice during the time period considered in the analysis.

7. State estimates indicate that 300,000 pounds are used annually (table 1). 2,4,5-T is applied at an average rate of 1 lb/A (active ingredient) one time per season (table 2). About 292,000 acres are treated aerially and about 8,000 acres of levees are treated by ground applicators for control of weeds (table 1). In the tables and discussions only the aerial applications are considered because (1) levee spraying is a new management practice, (2) other herbicide substitutes, such as propanil, silvex, 2,4-D, and MCPA control weeds ineffectively and probably would not be used by farmers to manage weeds on levees, (3) rice yields are naturally low on levees and weed infestations on these sites would have less impact on yield than in the flooded paddy, and (4) data are not available to assess the impact of weed infestations on levees. Therefore, we did not consider levee applications in the economic analysis.

In the 2,4,5-T use areas of Arkansas, Mississippi, northern Louisiana, and Missouri, about 1.1 million acres were grown in 1975-77 (table 3). This includes all of the harvested rice in Arkansas, Mississippi, and Missouri and 62,000 acres in northern Louisiana. 2,4,5-T is not used for weed control in rice in the southwest rice-growing area of Louisiana.

8. Silvex contains TCDD similiar to 2,4,5-T (Helling et al. 1973). It controls most of the weeds that infest rice as effectively as 2,4,5-T (table 4). Because it injures soybeans and cotton more than 2,4,5-T, it cannot be used as extensively as 2,4,5-T

Table 1--Estimated rice acreage and percentage treated with specific herbicides, major rice states, 1975-1977

State	Total rice Acreage[a/]	Herbicide[b/] Propanil	Molinate	2,4,5-T[c/]		2,4-D	MCPA	Silvex	Bifenox	Bentazon	Oxadiazon[d/]
	1,000 acres	1,000 acres treated									
Arkansas	855	846	342	177	(172)	129	0	2	5	e/	0
Texas	519	509	311	0		26	52	0	100	e/	0
Louisiana	567	454	113	18	(17)	170	0	0	2	e/	0
Mississippi	142	140	71	101	(99)	7	0	0	2	0	0
Missouri	16	15	4	4	(d)	0	0	0	0	0	0
California	411	12	329	e/		e/	358	0	0	0	0
Total	2,510	1,976	1,170	300	(292)	332	410	2	109	e/	0
	Percent	Percent treated									
Arkansas	100	99	40	21		15	0	f/	f/	f/	0
Texas	100	98	60	0		5	10	0	19	f/	0
Louisiana	100	80	20	3		30	0	0	f/	f/	0
Mississippi	100	99	50	71		5	0	0	1	f/	0
Missouri	100	95	25	25		0	0	0	0	0	0
California	100	3	80	f/		f/	87	0	0	0	0
Total[g/]	100	79	47	12		13	16	f/	4	f/	0

a/ Table 5.

b/ Data derived from official state records when available, from surveys, and from estimates made by

continued

Table 1--Estimated rice acreage and percentage treated with specific herbicides, major rice states, 1975-1977 (continued)

professional workers in given areas. Personal communications from John B. Baker, LSU, Baton Rouge, LA, June 23, 1978; Ted Miller and Don Bowman, MSU, Stoneville, MS, June 23, 1978; Harold Kerr and Joe Scott, Delta Center, U. Missouri, Portageville, MO, June 19, 1978; Ford Eastin, Texas A&M University, Beaumont, TX, June 21, 1978; Don Seaman, U of CA, Biggs, CA, June 20, 1978; Ford Baldwin, Cooperative Ext. Serv., Little Rock, AR, June 1978.

c/ Includes aerial and ground (levee spraying) applications -- 292,000 and 8,000 acres, respectively, for aerial and ground (levee) applications, this would be the levees on 50,000 acres of rice. Values in parenthesis are acres treated aerially. Spraying of 2,4,5-T on levees will not be considered in further discussions. In Louisiana, 2,4,5-T is used is the northern Mississippi River Delta rice-growing area (62,000 acres), but not in the southwestern rice-producing area. The U.S. Department of Agriculture estimates that 400,000-600,000 lbs of 2,4,5-T are used on rice each year; these estimates are probably high (U.S. Dept. of Agri. 1978).

d/ This herbicide was not registered in 1977, but was in 1978.

e/ Less than 1,000 acres treated.

f/ Less than 1%.

g/ Percentages calculated from acreage treated with each herbicide.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

Table 2--Estimated cost of using 2,4,5-T by aerial application in rice areas, 1975-1977[a/]

Item	Unit	2,4,5-T Arkansas	2,4,5-T Mississippi	2,4,5-T Louisiana	2,4,5-T Missouri	2,4,5-T + 2,4-D Arkansas	Total
Herbicide quantity per acre[b/]	lb	1.0	1.0	1.0	1.0	1.5[c/]	
Cost per pound[d/]	dol	5.50	5.50	5.50	5.50	4.45[e/]	
Herbicide cost per acre	dol	5.50	5.50	5.50	5.50	6.70	
Application cost per acre[f/]	dol	4.00	5.00	5.00	5.00	4.00	
Total herbicide cost/acre	dol	9.50	10.50	10.50	10.50	10.70	
Treated[g/]	acres	112,000	99,000	17,000	4,000	60,000	292,000
Total area cost	dol	1,064,000	1,040,000	178,000	42,000	642,000	2,966,000

a/ 292,000 acres applied aerially (table 1).

b/ Herbicide rate based on active ingredients.

c/ 0.75 lb/A of each herbicide used.

d/ Arkansas Cooperative Extension Service (1978e)

e/ Composite cost of 2,4,5-T and 2,4-D when estimated prices were $5.50 and $3.40 per pound.

f/ Arkansas Cooperative Extension Service (1978e) and Mullins et al. 1978.

g/ Acreage (8,000 acres) treated by ground applicators (levees) ommitted.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

Table 3--Rice acreage, per acre yield, production, and value in 2,4,5-T use area, 1975-1977

State	Acres harvested[a]	Production[a],[b]	Value of production[a],[c]
	1,000 acres	1,000 cwt	1,000 dollars
Arkansas	855	38,604	323,000
Mississippi	142	5,718	46,000
Louisiana	62	2,358	18,000
Missouri	16	658	6,000
Total	1,075	47,338	393,000

a/ Data from table 5 and from the Rice Journal, 1978 for Louisiana.

b/ Average yield per acre = 44 cwt (47,338,000 ÷ 1,075,000).

c/ Average value per acre = $366 (393,000,000 ÷ 1,075,000).

SOURCE: USDA-SEA-AR, Stuttgart, AR.

Table 4--Control of common rice field weeds by selected herbicides[a]

Weed	Herbicide								
	Propanil	Molinate	2,4,5-T	2,4-D	MCPA	Silvex	Bifenox	Bentazon	Oxadiazon
Alligatorweed (*Alternanthera philoxeroides*)	2	2	5	6	5	5	4	2	2
Arrowhead (*Sagittaria* spp.)	2	2	6	6	6	6	2	2	2
Barnyardgrass (*Echinochloa* spp.)	9	9	0	0	0	0	6	0	8
Beakrush (*Rhynchospora corniculata*)	6	3	8	8	8	8	5	6	5
Broadleaf signalgrass (*Brachiaria platyphylla*)	8	6	0	0	0	0	8	0	8
Bulrush, roughseed (*S. mucronatus* L.)	6	9	8	9	9	8	3	8	2
Bulrush, river (*S. fluviatilis* (Torr.))	2	0	2	2	2	7	3	8	2
Burhead (*Echinodorus cordifolius*)	2	0	8	9	9	8	3	6	3
Cattail (*Typha* spp.)	2	2	6	6	6	6	2	6	2
Cocklebur (*Xanthium* spp.)	4	2	9	9	9	9	5	9	5
Dayflower[a] (*Commelina diffusa*)	5	5	9	9	9	9	8	9	8
Ducksalad (*Heteranthera* spp.)	5	0	6	9	6	6	8	5	8
Eclipta (*Eclipta alba*)	8	8	9	9	9	9	8	6	8
False pimpernel (*Lindernia* spp.)	7	0	9	9	9	9	8	7	8
Fimbristylis (*Fimbristylis* spp.)	8	4	8	8	8	8	8	7	8
Gooseweed (*Sphenoclea zeylanica*)	5	2	8	6	6	7	8	7	8

continued

Table 4--Control of common rice field weeds by selected herbicides[a/] (continued)

Weed	Herbicide								
	Propanil	Molinate	2,4,5-T	2,4-D	MCPA	Silvex	Bifenox	Bentazon	Oxadiazon
Hemp sesbania (*Sesbania exaltata*)	9	2	9	9	6	9	6	4	6
Horned pondweed (*Zannichellia palustris*)	3	0	6	8	8	6	8	5	8
Jointvetch, northern (*A. virginica*)	6	2	9	5	4	8	5	4	5
Jointvetch, Indian (*A. indica*)	6	2	9	5	4	8	5	4	5
Knotgrass (*Paspalum* spp.)	4	2	0	0	0	0	4	0	4
Mexicanweed (*Caperonia castaneaefolia*)	3	3	8	6	6	7	8	5	8
Morningglory (*Ipomoea* spp.)	2	0	9	9	9	9	5	3	6
Naiad (*Najas* spp.)	0	0	0	0	0	0	6	2	6
Panicum grass (annuals) (*Panicum* spp.)	8	8	0	0	0	0	8	0	8
Pondweed (*Potamogeton* spp.)	2	2	6	6	6	6	4	2	4
Red rice (*Oryza sativa* L.)	0	7	0	0	0	0	0	0	0
Redstem (*Ammannia* spp.)	5	2	9	9	9	8	8	8	9
Smartweed (*Polygonum* spp.)	5	4	7	6	6	6	6	8	6
Spikerush (annuals) (*Eleocharis* spp.)	8	7	8	8	7	6	6	8	8
Sprangletop[b/] (*Leptochloa* spp.)	5	0	0	0	0	0	8	0	7
Umbrellaplant (annuals) (*Cyperus* spp.)	7	6	7	7	7	7	8	8	8

continued

Table 4--Control of common rice field weeds by selected herbicides[a/] (continued)

Weed	Herbicide								
	Propanil	Molinate	2,4,5-T	2,4-D	MCPA	Silvex	Bifenox	Bentazon	Oxadiazon
Umbrellaplant (perennials) (*Cyperus* spp.)	6	5	6	6	6	6	6	8	6
Waterhyssop (*Bacopa rotundifolia*)	8	2	9	9	9	9	8	8	8
Waterprimrose (*Jussiaea* spp.)	2	2	7	6	5	6	7	6	7

a/ Data adapted from Smith et al 1977; Arkansas Agriculture Extension Service (1978a,b, and f). Susceptibility of weeds based on data taken from greenhouse and field experiments and from observations made in ricefields from general applications. Scale: 0 = no control; 10 = 100% control. Reviewed by John B. Baker, LSU, Baton Rouge, LA, June 23, 1978; Ted Miller and Don Bowman, MSU, Stoneville, MS, June 23, 1978; Harold Kerr and Joe Scott, Delta Center, U of Missouri, Portageville, MO, June 19, 1978; Ford Eastin, Texas A&M University, Beaumont, TX, June 21, 1978; Don Seaman, U of California, Biggs, CA, June 20, 1978; Ford Baldwin, Cooperative Ext. Serv., Little Rock, AR, June 1978.

b/ Tank mixture of propanil + molinate gives a control rating of 8.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

in the rice areas of the Mississippi River Valley where sprays from target ricefields may drift and damage nearby soybeans and cotton. MCPA is considered not to be a substitute for 2,4,5-T because it fails to control common leguminous weeds such as hemp sesbania and northern jointvetch (table 4). Recently registered herbicides such as bifenox, bentazon, and oxadiazon cannot substitute for 2,4,5-T because they fail to control many of the weeds controlled by 2,4,5-T (table 4). Bifenox is registered under a Section 24C label in Arkansas, Louisiana, Mississippi, and Texas. Bentazon is registered under a Section 24C label in Arkansas, Mississippi, and Texas. Oxadiazon is registered under a Section 24C label in Arkansas, Louisiana, and Texas (Arkansas Cooperative Extension Service, 1978e).

9. Although ground applicators could be used for general or entire-field applications of phenoxy herbicides such as 2,4-D, use of such equipment will damage rice growth and rice levees, which makes required water management practices very difficult (Gerlow 1973). Also, ricefields would have to be drained to make ground applications; this would disrupt optimum production inputs. In addition 2,4-D damages rice if not applied at precise stages of rice growth. Therefore, use of ground spray equipment at this time is highly questionable and is not considered a viable alternate to 2,4,5-T.

RICE PRODUCTION IN THE UNITED STATES

MAJOR RICE-PRODUCING AREAS OF THE U.S.

The major rice-producing areas of the United States are located in four southern states (Arkansas, Louisiana, Texas, and Mississippi) and California; a small acreage is grown in southern Missouri (fig. 1 and tables 5 and 6). Arkansas, Louisiana, Texas, Mississippi, and Missouri produced about 84 percent and California about 15 percent of the 1975-77 production. About 1 percent of the rice is produced in other states.

Table 5--Acres, production, and value of rice, United States, Arkansas, Louisiana, Texas, California, Mississippi, and Missouri, 1975-1977 a/

Area and year	Acres Planted	Acres Harvested	Yield per acre	Production	Value per CWT b/	Value per acre	Value of production
	1,000 acres	1,000 acres	Pounds	1,000 CWT	Dollars	Dollars	1,000 Dollars
United States:							
1975	2,818	2,802	4,567	127,972	8.35	381	1,068,566
1976	2,489	2,480	4,663	115,648	7.02	327	811,849
1977	2,261	2,249	4,412	99,223	9.43 b/	416	935,673
1975-77 Avg. -	2,523	2,510	4,547	114,281	8.21	373	938,696
Arkansas:							
1975	885	882	4,540	40,053	8.54	388	352,053
1976	850	847	4,770	40,362	7.25	346	292,624
1977	840	837	4,230	35,396	9.43	399	333,784
1975-77 Avg. -	858	855	4,515	38,604	8.36	377	322,820
Louisiana:							
1975	660	658	3,810	25,064	8.38	319	210,036
1976	570	568	3,910	22,203	6.53	255	144,985
1977	480	475	3,670	17,445	9.43	346	164,506
1975-77 Avg. -	570	567	3,804	21,571	8.03	305	173,176

continued

Table 5--Acres, production, and value of rice, United States, Arkansas, Louisiana, Texas, California, Mississippi, and Missouri, 1975-1977 a/ (continued)

Area and year	Acres: Planted	Acres: Harvested	Yield per acre	Production	Value per CWT b/	Value per acre	Value of production
	------1,000 acres---		Pounds	1,000 CWT	-------Dollars---------		1,000 Dollars
Texas:							
1975	550	548	4,560	24,996	8.81	402	220,215
1976	510	508	4,810	24,430	7.21	347	176,140
1977	502	501	4,670	23,400	9.43	440	220,662
1975-77 Avg. -	521	519	4,677	24,275	8.47	396	205,672
California:							
1975	530	525	5,800	30,436	7.50	435	228,270
1976	400	399	5,520	22,017	6.50	359	143,111
1977	310	308	5,810	17,913	9.43	548	168,920
1975-77 Avg. -	413	411	5,710	23,455	7.68	438	180,100
Mississippi:							
1975	175	171	3,900	6,665	8.42	328	56,119
1976	145	144	4,200	6,048	6.79	285	41,066
1977	112	111	4,000	4,440	9.43	377	41,869
1975-77 Avg. -	144	142	4,027	5,718	8.11	327	46,351

continued

Table 5—Acres, production, and value of rice, United States, Arkansas, Louisiana, Texas, California, Mississippi, and Missouri, 1975-1977 a/ (continued)

Area and year	Acres: Planted	Acres: Harvested	Yield per acre	Production	Value per CWT b/	Value per acre	Value of production
	------1,000 acres---		Pounds	1,000 CWT	-------Dollars--------		1,000 Dollars
Missouri:							
1975	18	18	4,210	758	8.54	360	6,473
1976	14	14	4,200	588	7.25	304	4,263
1977	17	17	3,700	629	9.43	349	5,931
1975-77 Avg. -	16	16	4,113	658	8.44	347	5,556

a/ Preliminary data in many cases for 1977. Data from USDA-ESCS 1977 and 1978, Mullins et al. 1978.

b/ Season average price for U.S. and States for 1975 and 1976. Preliminary season average price for U.S. for 1977. Season average price for States for 1977 not available until approximately January, 1979.

SOURCE: USDA-SEA-AR Stuttgart, AR and Natural Resource Economics Division, USDA-ESCS, Corvallis, OR.

Table 6--Rice harvested, yield per acre, production, and value, selected states, 1975-77 a/ (Summary of table 5).

State	Acres harvested	Yield per acre	Production	Value
	1,000 acres	Pounds	1,000 cwt	1,000 dollars
Arkansas	855	4,515	38,604	323,000
Louisiana	567	3,804	21,571	173,000
Texas	519	4,677	24,275	206,000
Mississippi	142	4,027	5,718	46,000
Missouri	16	4,113	658	6,000
California	411	5,710	23,455	180,000
U.S. Total b/	2,510	26,846	114,281	934,000

a/ Average for 1975-77. See table 5 for detailed data.

b/ Totals may not sum or average because of rounding numbers.

In Arkansas, the rice areas are located in three separate geographical regions (Gerlow 1973). The Grand Prairie area is in the east-central part, including most of Arkansas, Lonoke, and Prairie Counties and a small part of Monroe County. The northeastern area bounded by Crowley's Ridge and the White, Black, and Mississippi Rivers, and includes parts of 15 counties. The southeastern area is composed primarily of five counties located in the Arkansas-Mississippi River Delta.

In Louisiana, the rice area lies in two separate regions. The older and larger southwestern area is located in nine parishes. The northern area is primarily in the Mississippi River Delta in 10 northeastern parishes. The Mississippi rice area is located in 15 west-central Mississippi River Delta counties. The Missouri rice area is located in the south-central boot heel area where two counties produce 90 percent of the rice. The Texas rice area lies primarily along the Gulf Coast in 20 southeastern counties.

The major rice-growing area in California is found in eight counties in the northern part of the Sacramento Valley. A small acreage of rice is also grown in eight counties in the San Joaquin Valley.

CONSUMPTION AND MARKETING OF RICE IN THE U.S.

The average value of the 1975-77 rice crop was approximately $934 million annually (table 5). In most states where rice is produced, the crop represents a major source of agricultural income and is highly important to large sectors of the rural economy.

Annual per capita consumption of rice averages about 10 pounds in the U.S. (USDA-ESCS 1978). Although the amount consumed continues to increase, production has always exceeded domestic consumption and large quantities are exported. During the 1975-77 period, approximately 60 percent of total U.S. rice production was exported (USDA-ESCS 1978). About 64 percent of this quantity was for dollar sales and the remainder was exported under various Government programs--mainly P.L. 480 (USDA-ESCS 1978).

The quantity of rice which moves within domestic channels including Puerto Rico, is exported for dollars or under P.L. 480 varies among states (table 7). About 48 percent of Arkansas and Mississippi rice is marketed domestically, about 43 percent goes for dollar exports, and 9 percent is exported under P.L. 480. For Louisiana, 44 percent of the rice is marketed through domestic channels, 23 percent through dollar exports, and 33 percent through exports under P.L. 480. In Texas, the figures are 33 percent, 62 percent, and 5 percent, respectively.

These marketing patterns indicate that Arkansas and Mississippi (high 2,4,5-T use areas) (table 1) are selling about 91 percent of their rice in domestic and dollar export markets which demand high quality rice. Therefore, production changes, such as elimination of 2,4,5-T, which affect the quality of rice produced in these states can adversely affect their markets and prices.

RICE PRODUCTION AND WEED MANAGEMENT GOALS

The goal of the U.S. rice industry is to produce adequate supplies of grain for domestic and foreign markets (Gerlow 1973). In addition, marketing and distribution systems that presently exist are maintained by adequate supplies of high-quality rice grain. Arkansas, Mississippi, northern Louisiana, and Missouri produce much of the high-quality long grain rice consumed domestically (table 7). The high-quality rice produced in these areas is also exported to foreign countries for dollar sales and its value contributes to the foreign exchange of the U.S. If this area is unable to meet domestic demand for high-quality rice, other rice-producing states would shift some of their high-quality export rice into these markets. Such shifts would alter existing marketing channels and seriously deter marketing agencies now active in Arkansas, Mississippi, northern Louisiana, and Missouri. Exports of inferior-quality rice could mean losses in dollar sales. Furthermore,

Table 7—Shipments of milled rice, marketing years 1975-1976[a/]

Location and source	Aug. 1975- July 1976	Aug. 1976- July 1977	Average 1975-1976	Percent
	-----	1,000 cwt	-----	
Arkansas & Mississippi				
Marketed domestically	10,890	12,360	11,620	48
Dollar exports	8,950	11,740	10,340	43
PL-480 exports	2,800	1,610	2,200	9
Total	22,640	25,710	24,160	
Louisiana				
Marketed domestically	5,220	4,510	4,860	44
Dollar exports	1,540	3,680	2,610	23
PL-480 exports	2,550	4,790	3,670	33
Total	9,310	12,980	11,140	
Texas				
Marketed domestically	6,820	8,000	7,410	33
Dollar exports	11,660	15,810	13,740	62
PL-480 exports	730	1,360	1,040	5
Total	19,210	25,170	22,190	

a/ Data from The Rice Millers' Association, 1978b. No data from California available.

the rice carryover could increase and the U.S. industry would have more rice to move through Federal programs that use rice with lower quality. If 2,4,5-T were unavailable and propanil or 2,4-D were substituted, low-quality rice would be produced because grain would be contaminated with weed seed.

The objectives of weed management in a rice-production system are: (1) to prevent or minimize losses in yield due to weed competition; (2) to prevent or minimize quality losses and subsequent lower value of rough and milled rice; and (3) to permit highly efficient use of costly production inputs e.g. high-yielding varieties, fertilizers, insect and disease control, and irrigation water (Smith et al. 1977).

To implement an effective weed-management program in rice, the interdependence of cultural-mechanical-crop management practices and herbicides must be recognized (Smith et al. 1977). When either is used alone, effective weed control is often not obtained. When cultural-mechanical systems fail to control weeds in rice (and they are usually inadequate), herbicides are necessary to reduce losses from weeds.

When weed grasses develop in ricefields because of improperly managed or ineffective cultural-mechanical systems, timely applications of effective rates of propanil or molinate reduce losses from grass weeds (Smith et al. 1977). Likewise, when aquatic, broadleaf, and sedge weeds infest ricefields, timely treatments with phenoxy herbicides can reduce yield and quality losses to these weeds. Usually cultural-mechanical systems fail to give effective weed control in most ricefield environments.

By combining control methods into effective systems, most weeds in rice can be controlled (Smith et al. 1977). Consequently, high yields of good-quality rice can be produced with a minimum of labor and machinery. Effective weed control also permits the rice farmer to select seeding methods, varieties, irrigation, and fertilizer practices, insect and disease-control programs that favor rice growth and production.

Rice farmers are presently using 2,4,5-T on about 300,000 acres of rice in Arkansas, Mississippi, northern Louisiana, and Missouri (table 1). 2,4,5-T is a basic weed control input into an integrated weed-management program for rice in the 2,4,5-T use area (Smith et al. 1977). Although other herbicides are used in weed-control programs for rice, they are not as effective on as broad a spectrum of broadleaf weeds as 2,4,5-T (table 4). Propanil and 2,4-D control many of the same broadleaf, aquatic, and sedge weeds as 2,4,5-T, but they fail on other species (table 4). Therefore, no combination of use patterns for propanil and 2,4-D will match 2,4,5-T for efficacy.

Cotton is frequently grown nearby ricefields in the 2,4,5-T use area (Baldwin 1978). Because this crop is very susceptible to 2,4-D damage from spray drift (Smith et al. 1977), this herbicide cannot be used in much of the 2,4,5-T use area. When 2,4-D damages cotton, yields and quality are reduced with subsequent income loss to the farmer. Also, judicial, social, and political problems may develop as a result of the damaged cotton. Therefore, 2,4,5-T is needed to control weeds in rice and to prevent the necessity of using herbicides more toxic to nontarget crops than 2,4,5-T. This herbicide injures cotton less than 2,4-D (Smith et al. 1977).

Soybeans, which are rotated with rice in the 2,4,5-T use area, are highly susceptible to silvex (Smith et al. 1977). Thus, this herbicide cannot be used on a significant portion of the rice presently treated with 2,4,5-T because spray drift could injure the crop and reduce yields.

Although cultural-mechanical-crop management practices help reduce weed problems in rice, they give best control when integrated with herbicide treatments (Smith et al. 1977). Phenoxy herbicides such as 2,4,5-T are essential in an integrated weed-management program for rice. They control the broadleaf, aquatic, sedge weed complex that develops in ricefields treated with any combination of cultural-mechanical-crop management practices.

Weeds reduce the yield and quality of rice in the U.S. by an estimated 15 percent each year on approximately 2.5 million acres; the loss was valued at about $165 million annually in 1975-77 (Smith et al. 1977). The cost of using herbicides to prevent greater losses was about $60 million each year during the same period (table 8). Also, the cost of cultural practices (including rotations, land preparation, irrigation, and fertilization), prorated to control weeds was estimated at $70 million (Smith et al. 1977). Thus, the total estimated direct losses from weeds and expenditures for their control were $295 million annually for the 1975-77 period.

Losses would exceed 50 percent in many ricefields that are heavily infested with weeds if herbicides were not applied to control the weed complex (Smith et al. 1977).

Herbicide usage in rice has steadily increased as effective herbicides have been developed. About 81 percent of the commercial rice in the U.S. was treated with one or more herbicides in 1968, up from 78 percent in 1965 and 53 percent in 1962 (Smith et al. 1977). Since 1968, herbicide usage in rice has continued to increase to where an estimated 98 percent of the acreage is now treated each year with at least one application. Frequently, ricefields are treated two or three times each year with various herbicides. Custom aerial applicators apply herbicides to 87 percent or more of the rice acreage while farmers apply the remainder (Smith et al. 1977).

Effective weed-control systems combine preventive, cultural, mechanical, chemical, and biological methods (Smith et al. 1977). Nonchemical methods may include some or all of the following practices: planting weed-free seed, crop rotation, levelling land, seedbed preparation, selecting the proper seeding method, and managing water and fertilizers properly. Chemical methods involve the use of herbicide treatments that selectively control weeds in rice when applied correctly. The weed

Table 8--Expenditures per acre for herbicides and their application for weed control in rice, 1975-1977

State	Acres harvested[a/]	Cost/Acre[b/]	Total expenditures
	1,000 Acres	Dollars	1,000 Dollars
Arkansas	855	31	26,505
Louisiana	567	16	9,072
Texas	519	26	13,494
California	411	16	6,576
Mississippi	142	33	4,686
Missouri	16	33	528
Total			60,861

a/ Data from Table 5.

b/ Average 1975-1977. Herbicide costs extrapolated from estimated costs and returns per acre of rice in major producing areas, 1975 season, Texas Agr. Exp. Sta. Dep. of Economics 1975, Mullins et al. 1978.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

management system that omits any one of those components is often inadequate. Therefore, combination treatments of several cultural and herbicide practices are essential to control weeds effectively in rice production. Several herbicide treatments applied in mixtures or in sequence may be required for effective weed control. 2,4,5-T is an important component of an effective weed-control program for rice (Arkansas Cooperative Extension Service 1978f; Smith et al. 1977). This herbicide controls broadleaf, aquatic, and sedge weeds that infest ricefields better than other herbicides (table 4) and it is less injurious to nontarget crops than other phenoxy herbicides (Smith et al. 1977).

Conditions favorable for growing rice are also favorable for the growth and reproduction of many terrestrial, aquatic, and semiaquatic weeds (Smith et al. 1977). Table 4 lists the principal grass, broadleaf, aquatic, and sedge species that cause major losses in U.S. rice production. Weeds in rice produce an abundance of viable seed and other propagules, and once these infest the land, they are difficult to remove and may remain viable in the soil for many years. The broadcast and drill seeding of rice reduce the opportunity for cultivation after emergence to remove weeds. Thus, the use of herbicides for controlling weeds is of prime importance in a weed-management program for rice.

Herbicides registered for use in rice and their activity on important weeds are presented in table 4. Generally, herbicides registered for use in rice may be classed into three groups: (1) those that control grass weeds, which are propanil and molinate; (2) those that control broadleaf and aquatics weeds, which include the phenoxy herbicides (2,4,5-T, 2,4-D, MCPA, and silvex) and bentazon; and (3) those that control grass, broadleaf, aquatic, and sedge weeds which are bifenox and oxadiazon. These latter two herbicides were registered for use in rice only recently, and their use in rice is still small (table 1); also, they must usually be combined with propanil to satisfactorily control an adequate spectrum of weeds (Arkansas Cooperative Extension Service 1978f). Copper compounds (copper sulfate and copper complexes) are used for control of green and blue-green filamentous algae in rice, but their efficacy is erratic (Smith et al. 1977). Endothall is used in California (State 24 C label) for control of submerged aquatic weeds in rice (Seaman 1978), but it is not effective on the emersed aquatic weed complex of rice in the southern rice-producing area (USDA-SEA-AR 1978).

Frequently, herbicides registered for use in rice are tank mixed to increase the number of weed species controlled and to combine the attributes of each. Examples are: (1) a mixture of a postemergence herbicide with a preemergence one; or (2) a mixture of a herbicide active on grass weeds and one active on broadleaf weeds. Commonly used mixtures include propanil + molinate, propanil + 2,4,5-T, propanil + silvex, propanil + bentazon, and propanil + oxadiazon (Arkansas Cooperative Extension Service 1978f, USDA-SEA-AR 1978).

POTENTIAL SOLUTIONS FOR THE PROBLEM

Effective weed-management systems for rice require the integrated use of cultural-mechanical-crop management practices and herbicides (Smith et al. 1977). Cultural-mechanical-crop management practices help reduce weed problems, but they alone are inadequate in controlling weeds and preventing losses in yield and quality. The wise use of crop rotation systems helps reduce problems with many weeds; e.g. red rice, perennial grasses, broadleaf, and aquatic weeds, and annual broadleaf and aquatic weeds that are susceptible to 2,4,5-T. Preplant land preparation, special seeding practices, and water management also help reduce weeds that are susceptible to 2,4,5-T. However, many weeds that develop after seeding the rice crop are controlled only by the use of 2,4,5-T and other herbicides. Weed control is a continuing operation. Failure to keep weeds continuously under control will lead to a buildup of weed populations that affect rice and crops rotated with rice. Thus, a well-developed and integrated control program cannot be turned on and off without serious consequences.

Several herbicides are registered for use in rice. They are propanil, molinate, 2,4,5-T, 2,4-D, MCPA, silvex, bifenox, bentazon, and oxadiazon (tables 1 and 4). Propanil and molinate are the most widely used herbicides; they are principally active for control of grass weeds. However, propanil controls certain broadleaf and aquatic weeds that are susceptible to 2,4,5-T (table 4). The phenoxy herbicides--2,4,5-T, 2,4-D, MCPA, and silvex--control many broadleaf, aquatic, and sedge weeds that infest rice. Bifenox, bentazon, oxadiazon, and endothall are herbicides that have only recently been registered for use in rice (Arkansas Cooperative Extension Service 1978f, Seaman 1978). They all have tolerances established on rice but are registered for use in rice in specific rice-growing States under the special needs category (provided by Section 24C of FIFRA). Bifenox has been used commercially since 1976, bentazon since 1977, oxadiazon was registered for the first time in 1978, and endothall is used only in California for control of submerged aquatic weeds. Hence, only a small percentage of the rice acreage is presently treated with these new herbicides (table 1). They control some weeds that are susceptible to 2,4,5-T but do not control as many species of broadleaf, aquatic, and sedge weeds as does 2,4,5-T (table 4). They are frequently used in tank mixtures with propanil to increase the weed control spectrum.

The phenoxy group of herbicides must be applied to rice at precise stages of growth to prevent crop injury; also, their sprays may drift from ricefields and injure nontarget crops, e.g. cotton, soybeans, lespedeza and vegetables (gardens) (Smith et al. 1977). Of this group, 2,4,5-T is the safest one to use in areas where cotton is grown. It can also be applied safely to rice during early tillering stages of growth whereas 2,4-D and MCPA injure rice when applied at this early stage of growth. In addition, 2,4,5-T controls some broadleaf and aquatic weeds more effectively than 2,4-D or MCPA (table 4). Weeds included in this group are northern and Indian jointvetch, gooseweed, Mexicanweed, smartweed, and waterprimrose. Although silvex (ester) controls weeds about equally to 2,4,5-T (table 4), it is more injurious than 2,4,5-T to nontarget crops such as soybeans and cotton (Smith et al. 1977).

Therefore, silvex cannot be used as frequently as 2,4,5-T in rice-growing areas of Arkansas, Mississippi, Louisiana, and Missouri.

Consequently, other registered herbicides for weeds are not as effective as 2,4,5-T. Propanil, 2,4-D, MCPA, silvex, bifenox, bentazon, and oxadiazon used alone and in combination as tank mixture or sequential treatments can reduce losses caused by some weeds that 2,4,5-T controls (table 4). However, even when used as combination treatments, they do not control weeds sufficiently to prevent yield and quality losses or they damage nontarget crops too severely to be substituted for 2,4,5-T.

Many new herbicide candidates for rice are being researched each year by public and private institutions. Herbicides that have advanced beyond primary evaluations include butachlor, thiobencarb, sodium and potassium azide, triclopyr, oxyfluorfen, and acifluorfen (Southern Weed Science Society Research Reports 1975, 1976, 1977, 1978). These herbicides, used alone and in combination with each other or with propanil or molinate, control some of the weeds that are susceptible to 2,4,5-T. However, not one of them is comparable to 2,4,5-T from the combined standpoints of efficacy and safety to rice and nontarget crops. Many of these herbicides will probably never be registered for use in rice because of efficacy, phytotoxicity, or environmental problems.

An endemic anthracnose disease of northern jointvetch incited by the fungus Colletotrichum gloeosporioides f. sp. aeschynomene was discovered in 1969 at Stuttgart, Arkansas (Daniel et al. 1973). Water-spore suspensions in 10 gpa controlled 95 to 100 percent of the northern jointvetch in field trials from 1971-1977. The fungus is very virulent on northern jointvetch, a weed susceptible to 2,4,5-T but not to most other herbicides (table 4). It does not affect rice, soybeans, cotton, or common field forage and vegetable crops, or other weeds. Future research and development will determine if the fungus can be produced in sufficient quantities for general use for control of northern jointvetch. Registration requirements are also yet to be determined for fungi.

It is essential that research and development continue to find new, safe, and effective herbicides for rice. The U.S. Department of Agriculture, the State Agricultural Experiment Stations, and private industry are all working cooperatively to find new herbicides and biocontrol agents that are more effective than present control methods.

In summary, 2,4,5-T is an essential tool in a weed-management system for rice. When 2,4,5-T is combined with other herbicide treatments and with cultural-mechanical-crop management weed control practices, losses in rice can be reduced to a minimum. With an effective weed-control program, production inputs, e.g. fertilizers, insect and disease control practices, and irrigation water can be managed efficiently with subsequent efficient rice production (Smith et al. 1977).

RICE PRODUCTION AND WEED CONTROL

Established management goals of the rice industry in the U.S. are to: (a) develop and implement technology needed to assure an adequate supply of high-quality rice to meet domestic and foreign market demands; and (b) improve the quality of the environment for man and animals (Shaw 1976, USDA-ARS 1976, Joint Task Force SAES and USDA 1977). Weed control technology is essential to achieving these goals. The use of safe and efficient principles and practices of weed control that are integrated with other production and protection technology is essential to assuring a high-yielding ricefield agroecosystem that maintains and improves the quality of the environment.

BIOLOGY AND ECOLOGY OF PLANT COMMUNITIES

The biology of weeds is the establishment, growth, and reproduction of weeds as well as the influence of the environment on these processes (Klingman & Ashton 1975). The ecology of weeds is primarily concerned with the effects of climatic, physiographic, and biotic factors. Climatic relationships include light, temperature, water, wind, and atmosphere. Physiographic is concerned with soil factors, e.g. pH, fertility, texture, structure, organic matter content, carbon dioxide, oxygen, and water drainage; and topograhic factors, e.g. altitude, slope, and exposure to the sun. Biotic influences include plant relationships, e.g. competition, diseases, toxins, stimulants, parasitism, and soil flora; and animal interactions, e.g. insects, grazing animals, soil fauna, and man.

Many of the most common weeds of ricefields have broad tolerance to ecological factors (Fryer and Matsunaka 1977). For example, barnyardgrass grows in almost all ricefield environments throughout the world; it is considered the most widely distributed weed of ricefields (Holm et al. 1977). Rarer species, e.g. willowleaf morningglory, are associated with rice cultured on heavy clay soils of the Mississippi River Delta areas. Dayflower, another weed of limited distribution, is associated principally with the double cropping culture of rice practiced in Texas; but it also grows in the prairie-production areas in Arkansas.

Weed species of rice include various kinds of grass, broadleaf, aquatic, and sedge plants (table 4). Community composition of weeds is dependent on cultural practices, crop rotation, water and soil management, weed-control practices, and climatic and soil conditions (Smith et al. 1977). In dry-seeded and water-seeded rice of the southern rice-producing area, barnyardgrass is the most prevalent weed (Smith et al 1977); most of the weed control inputs are for the control of this one species (table 1). However, morningglory, cocklebur, pigweed, prickly sida, and others that grow primarily in an upland environment are troublesome on levees in both dry-seeded and water-seeded rice.

There are some distinct differences between the weed communities of dry-seeded and water-seeded rice (Smith et al. 1977). Semiaquatic species, e.g. hemp sesbania, northern jointvetch, and dayflower germinate while the stand of dry-seeded rice is being established. By the time ricefields are flooded, usually 4-6 weeks after seeding, these established species grow well in the floodwater. In contrast, the aquatic weed complex germinates and grows well in the aquatic environment of water-seeded rice. These emersed species, which include ducksalad, redstem, waterhyssop, gooseweed, false pimpernel, spikerush, and annual umbrellasedges, germinate with the rice crop in the flooded soil. They usually compete with the rice during the early season when the rice crop is being established. Weed-control practices, by necessity, differ because of the weed species associated with particular rice cultures.

Weed communities in ricefields are constantly changing with changing weed control technology (Smith et al. 1977). In the south, morningglories were not troublesome in ricefields before the extensive use of propanil. This herbicide, which often does not control morningglories, reduces infestations of barnyardgrass and other annual grasses on ricefield levees. Although grass control by the use of propanil has improved rice stands and yields on levees, the lack of grass competition has enhanced morningglory infestations on the levees. Although morningglories do not compete with rice or reduce yields as severely as barnyardgrass, their seeds, which are difficult to separate from rice grain, are harvested with the rice and subsequently reduce the grade and value of the rice crop. Rice grain that contains morningglory seeds requires costly handling procedures to remove the weed seed. Because 2,4,5-T controls morningglory weeds growing on levees, the use of this herbicide is essential to a weed-control program in rice-growing areas of Arkansas, Mississippi, Louisiana, and Missouri.

Other weed species that have increased in recent years because they are tolerant to propanil and molinate, include dayflower, northern jointvetch, smartweed, alligatorweed, arrowhead, gooseweed, Mexicanweed, and sprangletop (Smith et al. 1977). Many of these broadleaf species are controlled by 2,4,5-T (table 4). As weeds become tolerant during various growth stages to propanil and molinate, need for 2,4,5-T or other herbicides to control them will increase.

Some weeds are associated with specific soil types. Willowleaf morningglory, a weed susceptible to 2,4,5-T but not to propanil or molinate, is primarily a problem in rice grown on the heavy clay soil of the Mississippi River Delta areas (Smith et al. 1977). Conversely, dayflower is a problem weed on the silt loam soil of the prairie rice-growing areas of Arkansas.

WEED IMPACT ON COMMODITY YIELD AND QUALITY

Both the density of weeds in rice and the duration of weed-rice competition affect rice yields. In numerous field experiments with various rice varieties, yields decreased as weed density and duration of weed competition increased (tables 9 and 10).

Hemp sesbania populations of 5,000 to 43,000 plants per acre reduced yields from 10 to 40 percent when competition lasted all season (table 9). The same populations of northern jointvetch reduced yields from 4 to 19 percent when competition lasted all season. Hemp sesbania grows taller than northern jointvetch; hence, it shades the rice more and causes greater yield losses (Smith et al. 1977).

Broadleaf, aquatic, and grass weeds reduce yields when competition is during the early season (table 10). Ducksalad and barnyardgrass are much more competitive during the early season than are hemp sesbania and northern jointvetch. However, these latter two weeds reduced yields 6 to 8 percent when competition lasted for only 8 weeks. On the other hand, ducksalad reduced yields 15 percent when competition lasted for only 4 weeks. Effective herbicides must be applied early (before 4 weeks) in the growing season to prevent losses from ducksalad competition, and applied by midseason (8 weeks) to keep losses from competition of hemp sesbania and northern jointvetch to a minimum.

Natural ricefield infestations of hemp sesbania and northern jointvetch are not as uniform as those reported in table 10 (Smith et al. 1977). Natural ricefield infestations usually sparsely populate the entire

Table 9--Yield losses as influenced by density of hemp sesbania and northern jointvetch[a/]

Weed plants/acre	Hemp sesbania	Northern jointvetch
	--------% Loss in Yield--------	
5,445	10	4
10,890	15	7
21,780	27	11
43,560	40	19

a/ Data adapted from Smith 1968.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

Table 10--Yield losses due to weed competition[a/]

	Length of competition			
Weed	4 Weeks	8 Weeks	12 Weeks	All season
	--------% Loss in Yield--------			
Hemp sesbania	2	6	9	19
Northern jointvetch	2	8	8	17
Ducksalad	15	27	-	21
Barnyardgrass	8	35	43	70
Sprangletop	-	-	-	35

a/ Data adapted from Smith 1968 and Smith 1975.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

field or they grow in colonies in which not more than 25 percent of the land area is infested. In addition, a ricefield usually has a complex of both weeds. Thus, it is estimated that natural ricefield infestations of hemp sesbania and northern jointvetch range from 5 to 10 thousand plants per acre of each species. Therefore, full season competition of these two weeds may reduce rice yields an estimated 15 percent.

In 1974, hemp sesbania and northern jointvetch seeds were found in 33 percent of the rough rice samples on total production in the 2,4,5-T use areas of Arkansas, Mississippi, northern Louisiana, and Missouri (table 11). Discounts ranged from $0.11 per cwt for No. 2 grade to $2.78 per cwt for sample grade (table 12). These quality losses in the 2,4,5-T use areas of Arkansas, Mississippi, Louisiana, and Missouri were valued at $70 million annually during 1975-1977 and occur on ricefields that are not treated with 2,4,5-T or other herbicides for control of these species (Arkansas Cooperative Extension Service 1975).

Several species of morningglory infest rice in the 2,4,5-T use area, but not in rice fields treated with 2,4,5-T. Because most species grow primarily on levees, they cause only minor reductions in grain yield (an estimated loss of 1%). However, 46 percent of the rice grain in the 2,4,5-T use areas of Arkansas, Mississippi, Louisiana, and Missouri, is infested with morningglory seeds (table 11). For example, 15 percent of the grain contained enough seeds to lower the grade to U.S. No. 4. Morningglory seed reduced the grade and subsequent value of rough rice an estimated $12 million annually during 1975-1977.

MANAGEMENT STRATEGIES

Current weed-control technology for rice includes the integrated use of cultural, chemical, mechanical, ecological, and biological systems of control (Smith et al. 1977). These primary weed-control methods are supplemented by (a) the use of genetically improved and well adapted rice varieties, (b) improved crop management practices -- including

Table 11--Rice grain graded down because of weed seed in the 2,4,5-T use area, 1975-77[a/]

	Percent rough rice containing indicated weed seed	
U.S. grade	Hemp sesbania and Northern jointvetch	Morningglory
2	1	4
3	7	12
4	11	15
5	6	6
6	6	6
Sample	2	3
Total	33	46

a/ Data based on a rice mill survey conducted by the Arkansas Cooperative Extension Service (1975) on 50% of the rice grown in Arkansas in 1974.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

Table 12--Discounts of rough rice from weed seed in the crop, 1975-77[a/]

U.S. grade #	Discount
	Dol/cwt
1	0
2	0.11
3	0.22
4	0.33
5	0.78
6	1.33
Sample[b/]	2.78

a/ Data based on information collected by the Arkansas Cooperative Extension Service (1976) from the Rice Industry.

b/ A composite of all grades above grade 6.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

optimum time of seeding, optimum plant populations per acre, and optimum tillage practices, (c) better plant nutrition, (d) improved farm equipment and mechanized practices for weed control, (e) improved irrigation management, (f) weed-free crop seed and other principles and practices that reduce weed competition and losses, (g) plant pathogens and insects to control weeds, (h) field sanitation, (i) crop rotations, (j) and preventive methods (Shaw 1976).

These rice production and protection practices, and others, are integrated with high-yielding agroecosystems compatible with a quality environment (USDA-ARS 1976; Shaw 1976). The control of diverse weed species and populations requires an integrated systems approach that includes nonchemical and chemical methods. The chemical methods of control require a broad spectrum of herbicides, mixtures of herbicides, herbicide rotations, sequential herbicide treatments, and the use of diverse and increasingly innovative and complex application techniques and equipment.

Cultural-mechanical-crop management practices are important components of an effective weed control system for rice (Smith et al. 1977). Although rice farmers are presently implementing such technology effectively, they also must use advanced herbicide techniques to obtain effective weed management in ricefields. Effective herbicide technology includes the judicious use of propanil, molinate, 2,4,5-T, 2,4-D, MCPA, silvex, bifenox, and bentazon as well as some new or minor use herbicide, e.g., oxadiazon, endothall, copper complexes, and copper sulfate (Smith et al. 1977).

Effective herbicide strategies include the sequential use of propanil or molinate for control of grass weeds and 2,4,5-T or other phenoxy herbicides for control of broadleaf, aquatic and sedge weeds (Smith et al. 1977). When these combinations of herbicide treatments are used with effective cultural-mechanical-crop management practices, weed competition and subsequent losses of rice yield and quality can be eliminated or reduced to a minimum.

2,4,5-T

Patterns Of Use

Current Patterns Of Use

2,4,5-T is used each year for control of aquatics, broadleaf and sedge weeds in rice-growing areas of Arkansas, Mississippi, Louisiana, and Missouri. Approximately 300,000 acres of rice in these four states are treated with 2,4,5-T (table 1). The acreage treated with 2,4,5-T ranges from 3 percent in Louisiana to 71 percent in Mississippi. The average use rate of 1 lb/A would result in about 300,000 pounds of active 2,4,5-T being used each year for weed control in rice. About 97 percent of the 2,4,5-T is aerially applied with fixed-wing aircraft or helicopters (Smith et al. 1977). However, in the last 5 years, ground applicators (4 wheel drive light-weight machines) have been used to spray levees at midseason (Arkansas Cooperative Extension Service, 1978e).

Use by States

Arkansas: 2,4,5-T is used in all rice-growing areas of Arkansas (Arkansas State Plant Board 1967-77). In the Mississippi River Delta area, cotton is grown nearby or adjacent to rice. Phenoxy herbicides such as 2,4-D and silvex cannot be used safely in these areas because cotton or soybeans are very sensitive to it (Smith et al. 1977). Although MCPA is safer to use than 2,4-D (but not as safe as 2,4,5-T), it does not control some of the principal broadleaf weeds, e.g. hemp sesbania and jointvetch, as effectively as 2,4,5-T (Smith et al. 1977).

2,4,5-T is also used in the prairie areas of Arkansas because northern and Indian jointvetch are prevalent. These two species are controlled better by 2,4,5-T than by other herbicide treatments (table 4). In this area where cotton is infrequently planted, 2,4,5-T is tank-mixed with 2,4-D to increase the number of aquatics, broadleaf, and sedge species controlled (Arkansas State Plant Board, 1967-77).

Mississippi: 2,4,5-T is used in all rice-growing areas of Mississippi (Miller 1978, Peoples 1978). Like the Mississippi River Delta area of Arkansas, cotton is grown near rice. 2,4,5-T is the safest phenoxy herbicide to use in this area and is the principal one used (table 1).

Louisiana: 2,4,5-T is used in the northeastern rice-growing area of Louisiana where cotton is intercropped with rice (Wilson 1978). However, 2,4,5-T is not used in the southwestern rice-growing area; here, 2,4-D is used because it controls the weed complex effectively and can be used without damaging nontarget crops (Baker 1978).

Missouri: 2,4,5-T is used in all rice-growing areas of Missouri because cotton is frequently intercropped with rice (Scott 1978, Kerr 1978).

Texas: 2,4,5-T is not used in the rice-growing areas of Texas because MCPA and 2,4-D control the aquatic and broadleaf weeds effectively and are relatively safe on nontarget crops (Eastin 1978).

California: Because cotton is not intercropped with rice in the California rice-growing area, 2,4,5-T is seldom used for weed control. MCPA is the principal phenoxy herbicide used for control of the aquatic-broadleaf weed complex (Seaman 1978).

Formulations, Rates and Volumes of Spray Material

Water soluble liquid amines of 2,4,5-T are used to control weeds in rice. Those used include diethanol amine, triethanol amine, dimethyl amine, triethyl amine and isopropyl amine (Smith et al. 1977). Ester formulations of 2,4,5-T are not used for weed control in rice (Baldwin 1978).

2,4,5-T amine salts are applied at an average rate of 1 lb/A, but the range is 0.5 to 1.5 lb/A of acid equivalent (Arkansas Cooperative Extension Service 1978f). The rate depends on weed species, stage of growth of the rice, air and water temperatures, use with other herbicides, and other factors (Smith et al. 1977).

2,4,5-T is applied with low gallonage sprayers mounted on fixed-wing or helicopter aircraft (Smith et al. 1977). Volumes applied range from 3 to 10 gpa (Smith et al. 1977) Arkansas Cooperative Extension Service 1978f), but 3 gpa is the most commonly used volume for applying 2,4,5-T. State regulations require that 2,4,5-T not be applied at less than 2 gpa (Arkansas State Plant Board 1978). State regulations also require that 2,4,5-T be applied with drift control agents, such as particulating, foam, or inversion agents, or be applied in an aircraft system designed to reduce spray drift.

Application Equipment and Characteristics of Spray

Fixed-wing and helicopter aircraft sprayers are usually equipped with booms and nozzles. Other distribution systems include rotary brushes or screens, disks, hollow propellers, bifluid and foam nozzles, and venturi type; however, these systems are infrequently used (Smith et al. 1977).

Booms are made of corrosion-resistant material such as aluminum (Smith et al. 1977). To minimize drift of spray, the boom is placed as far below the wing as practical, usually about 1 foot, and is extended within about 3 feet of the wingtip. If the boom extends to the wingtip, the spray may be whirled upward in the wingtip vortices to cause excessive spray drift. State regulations require that the length of the boom shall not exceed 70 percent of the wing span (Arkansas State Plant Board 1978).

Nozzles for fixed-wing aircraft sprayers are made of corrosion-resistant materials such as aluminum, brass, or nylon (Smith et al. 1977). Each is equipped with a quick-cutoff diaphragm, screen, and jet. Spray droplet size is greatly affected by the angle at which the nozzles discharge the spray into the airstream. Smaller droplets occur when the nozzles are directed against or across the airstream than when they are directed with it. For 2,4,5-T spraying to ricefields the nozzles are directed with the airstream (Smith et al. 1977). State regulations require that nozzles shall be aimed back parallel to, or not to exceed an angle of 45° from the boom on fixed-wing aircraft or from the line of flight on helicopters (Arkansas State Plant Board 1978). Droplet size is also affected by pump pressure and nozzle orifice diameter (Smith et al. 1977). Most rice-growing states have regulations that specify the maximum operating pressure for aerial spraying of 2,4,5-T; this usually does not exceed 20 psi. Orifice size is geared to deliver 3 gpa; most frequently used orifices range from D-2 to D-4 (Eichler 1978a). A compromise is usually made between small droplets, which give thorough coverage but have a tendency to drift, and large ones, which settle fast but do not give adequate coverage (Smith et al. 1977). Sprays usually give adequate weed control if droplets range from 100 to 300 μm in diameter.

Spray pattern or distribution is important (Smith et al. 1977). Proper placement and spacing of nozzles along the boom help to distribute the spray evenly. Usually the spray pattern is improved if more nozzles are placed on the right side of the plane than on the left. The air is swirled from the right to left by the counterclockwise rotation of the propeller (facing the propeller). Spraying the proper swath width for the particular aircraft also improves spray distribution. The wingspan and the flying height of the airplane govern the swath width. For 2,4,5-T spraying, the swath is usually about equal to the wingspan of the airplane. The number of nozzles on the boom ranges from 20 to 40. The swath width usually ranges from 30 to 50 feet. Proper flying height improves spray pattern and reduces spray drift. Spray distribution is best when fixed-wing airplanes fly 10 to 15 feet above the crop, but spray drift is less when they fly lower. Fixed wing aircraft usually release 2,4,5-T from 5 to 10 feet above the crop; this gives adequate distribution and minimum drift. Helicopters release 2,4,5-T from 2 to 5 feet above the rice crop. State regulations require that the flying height of fixed-wing aircraft and helicopters release the spray not more than 10 feet above the crop (Arkansas State Plant Board 1978).

During the last 5 years, ground applications have been used to apply 2,4,5-T to levees for control of weeds (Arkansas Cooperative Extension Service 1978e). A light-weight, 4-wheel drive machine equipped with tank, pump, boom, and nozzles straddles the levee and sprays about a 5- to 6-foot swath. The spray is released just above the rice canopy in a volume of 15 to 20 gpa. Only a small percentage of the rice acreage in the 2,4,5-T use area is treated by ground applicators (table 1). General spray applications to entire ricefields are not suitable with these ground applicators because they damage the levees (Arkansas Cooperative Extension Service 1978e). If all the rice in the 2,4,5-T use area (1.1 million acres--table 3) were treated for levee weed control, only about 5 percent of the land or 50,000 acres would be treated by ground equipment (table 13). The 292,000 acres treated aerially with 2,4,5-T do not require ground applications to levees. Therefore, the total potential acreage requiring weed control inputs on levees is estimated to be less than 25,000 acres. Probably no more than 8,000 acres of levees are presently being treated by ground applicators. This represents the levees on about 50,000 acres of rice (USDA-SEA-AR 1978). Conventional pumps and nozzles are used to make ground applications to levees.

Stage of Rice Growth at Time of Treatment and Atmospheric Conditions

The stage of growth greatly influences the response of rice plants to 2,4,5-T (table 14). Very young rice (from emergence up to 3 weeks after emergence) may be injured severely or even killed by 2,4,5-T at rates required to control weeds. Rice treated from 3 weeks after emergence until the internodes are 0.5 inches long, is tolerant to 2,4,5-T (Smith et al. 1977, Arkansas Cooperative Extension Service 1978f). The most tolerant stage can be positively identified when the basal internode begins to elongate from 0.25 to 0.5 inches long. Rice may be injured by 2,4,5-T when the internode is longer than 0.5 inch and during the panicle formation and heading stages. Applications during the booting stage (panicle initiation to panicle emergence) reduce grain yields as much as 20 percent, increase height as much as 12 percent, and reduce bushel weight of grain as much as 2 percent (Smith et al. 1977). Rice is usually 20-30 inches tall when the internodes are 0.25 - 0.5 inch long; its canopy covers the water surface at the time of application when rice stands are normal (Smith et al. 1977). Therefore, rice and

Table 13--Land area in levees on a 40-acre ricefield with various slopes a/

Slope of land[b]	Land in levees[c]	
Percent	Acres	Percent
0.5	6	15.0
0.4	5	12.5
0.25	3	7.5
0.15	2	5

a/ Adapted from Hall et al 1963.

b/ Land suitable for rice has slopes of .01 to 0.5% (USDA 1973). Vertical distance between levees is 0.1 to 0.2 ft.; levees are constructed at lower vertical distance on flatter land (Huey 1977).

c/ Approximately 5 ft. of levee is unflooded.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

Table 14--Growth development of selected rice varieties[a]

Variety	Days from emergence to maturity[a]	Days from emergence to midseason[b],[c]	Days from midseason to draining[d]	Days from midseason to maturity[c]
Labelle	100	45	41	55
Belle Patna	102	47	41	55
Lebonnet	105	50	41	55
Bluebelle	107	52	41	55
Saturn	114	60	40	54
Nato	118	65	39	53
Starbonnet	128	70	44	58

a/ Average seeding date for Arkansas in May 3; 10 days allowed from seeding to emergence. Data taken from USDA-ARS 1973.

b/ Midseason is when internodes are 0.25 to 0.5 inch long. This is the time when most of the 2,4,5-T is applied for weed control (Smith et al. 1977).

c/ Data adapted from Huey 1977.

d/ Rice is drained after panicles droop, begin to brown, and lower grains are in the milk stage. This is usually about 14 days before maturity. (Huey 1977). Days from time 2,4,5-T is applied until time floodwater is drained from the ricefield when rice is almost mature.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

weeds intercept most of the spray before it reaches the floodwater. Rice at 3 weeks after emergence is 6 to 10 inches tall and does not canopy the floodwater or soil. When applications are made at this early stage, significant amounts of the spray reaches the floodwater or soil. However, when 2,4,5-T is applied early, the floodwater is usually drained before spraying to expose small weeds to the spray. Hence, the soil receives most of the 2,4,5-T. Weeds covered with water are not controlled by 2,4,5-T applications.

2,4,5-T is usually applied during the early morning (5-8 a.m.) or late afternoon (6-9 p.m.) when temperatures have cooled and wind velocities have decreased. Usually temperatures range from 70 to 90°F and wind velocities are less than 5 mph. State regulations do not permit spraying of 2,4,5-T when temperatures exceed 90°F and wind velocity exceeds 5 mph. (Arkansas State Plant Board 1978).

Reasonable (Potential) Levels Of Use

Troublesome broadleaf and aquatic weeds, including hemp sesbania, nothern jointvetch, ducksalad, morningglory, and redstem infest an estimated 860,000 acres of rice in Arkansas, Mississippi, northern Louisiana, and southern Missouri; this is an estimated 80 percent of the acreage in these four rice-producing areas (table 15). Other broadleaf, aquatic, and sedge weeds infest the same and additional acreage that the above five weeds contaminate. In these same rice-producing areas, only 292,000 acres are treated aerially each year with 2,4,5-T (table 1). Therefore, at least 568,000 acres of rice contain broadleaf, aquatic, and sedge weeds that can be controlled with 2,4,5-T (tables 1 & 15). Although some of these acres receive alternate weed-control practices, including applications of propanil, 2,4-D, silvex, and others (bifenox and bentazon), the weed complex susceptible to 2,4,5-T is severe enough to cause losses in yield and quality. Therefore, many of these acres would receive 2,4,5-T applications if adequate supplies were available and if farmers were not reluctant to use it because of damage to nontarget crops and consumer and environmental group protests.

An estimated 284,000 acres of untreated rice could be economically treated with 2,4,5-T in an effective weed-management system (table 15).

Table 15--Estimated potential use levels of 2,4,5-T in Arkansas, Mississippi, northern Louisiana, and Missouri (2,4,5-T use area)

Weed	Acres infested[a]	Potential acres for treatment with 2,4,5-T[b]
	--------1,000 acres--------	
Hemp sesbania	572	172
Northern jointvetch	518	155
Ducksalad	648	194
Morningglory	464	139
Redstem	324	98
Acres infested with one or more weeds	860	284

a/ Data from Table 17.

b/ Does not include 300,000 acres treated with 2,4,5-T. Estimates developed by the Arkansas Cooperative Extension Service (1978e) Baldwin (1978) and USDA-SEA-AR (1978).

SOURCE: USDA-SEA-AR, Stuttgart, AR.

Therefore, the acreage potential for treatment with 2,4,5-T is 576,000 acres or almost twice the amount presently treated. This expanded use would be worth about $14 million to rice farmers and the rice industry (table 16).

Costs for Use

The cost of using 2,4,5-T varies slightly with the rice-producing area (table 5). In Arkansas, there are two distinct use areas--the prairie and the Arkansas-Mississippi River Delta. In the prairie areas, where cotton is grown infrequently, 2,4,5-T is used alone or mixed with 2,4-D (Arkansas State Plant Board 1967-1977). The cost of using 2,4,5-T alone is $9.50 per acre on 112,000 acres for a total cost of more than $1 million. The cost of using the 2,4,5-T/2,4-D mixture is $10.70 per acre in Arkansas.

The per-acre cost of using 2,4,5-T in the Mississippi, Louisiana, and Missouri rice-producing areas is about the same (table 2). The cost of herbicide plus applications is about $10.50 per acre in these three states.

Effect of Use on Commodity Yield and Quality

2,4,5-T is applied aerially to 292,000 acres of rice in Arkansas, Mississippi, Louisiana, and Missouri (table 1). The principal weed species infesting these areas are hemp sesbania, northern jointvetch, ducksalad, morningglory, and redstem (table 15); these five species are controlled or reduced with 2,4,5-T applications (table 4). Other less prevalent weeds that are controlled by 2,4,5-T, include beakrush, burhead, cocklebur, dayflower, eclipta, false pimpernel, fimbristylis, Indian jointvetch, Mexicanweed, smartweed, spikerush, umbrellaplant, waterhyssop, and waterprimrose (table 4). Although these weeds cause losses in yield and grade of rough rice, they usually occur as weed complexes with the five species in table 15. Only infrequently do they occur alone with rice. When they occur as monocultures, frequently they infest only small areas of the field or infest only levees.

Table 16—Annual use and returns for 2,4,5-T and projected returns with alternative scenarios 1-3 years after 2,4,5-T becomes unavailable, rice-growing areas of Arkansas, Mississippi, Louisiana, and Missouri

Area & alternative treatment	Acres in area[a]	Treated acres[b]	Per acre treatment cost[c]	Total cost[d]	Per acre yield	Total production[e]	Value per cwt	Total value[f]	Total value less treatment costs	Loss with best alternative[g]
	---Thousands---		Dollars	Thousand Dollars	CWT	Thousand CWT	Dollars	---------Thousand Dollars---------		
Arkansas:										
2,4,5-T	855	172	9.50	1,634	45.2[a]	7,774.4	8.36[k]	64,994	63,360	
Silvex, 2,4-D & Propanil	855	172	N.A.	1,685	N.A.	7,601.8	--	63,038	61,353	2,007
Silvex		60	9.50	570	45.2[a]	2,712.0	8.36[k]	22,672		
2,4-D		60	7.40	444	44.3[h]	2,658.0	8.28[l]	22,088		
Propanil		52	12.90	671	42.9[i]	2,231.9	8.19[m]	18,278		
2,4-D & propanil	855	172	N.A.	1,580	N.A.	7,541.2		62,225	60,645	2,715
2,4-D		116	7.40	858	44.3[h]	5,138.8	8.28[l]	42,549		
Propanil		56	12.90	772	42.9[i]	2,402.4	8.19[m]	19,676		
2,4-D	855	172	N.A.	858	N.A.	7,339.6	N.A.	60,221	59,363	
2,4-D		116	7.40	858	44.3[h]	5,138.8	8.28[l]	42,549		
No Treatment		56	0.00	0	39.3[j]	2,200.8	8.03[n]	17,672		
Propanil	855	172	12.90	2,219	42.9[i]	7,378.8	8.19[m]	60,432	58,213	
No Treatment	855	172	0.00	0	39.3[j]	6,759.6	8.03[n]	54,280	54,280	

continued

Table 16--Annual use and returns for 2,4,5-T and projected returns with alternative scenarios 1-3 years after 2,4,5-T becomes unavailable, rice-growing areas of Arkansas, Mississippi, Louisiana, and Missouri (Continued)

Area & alter- native treatment	Acres in area[a/]	Treated acres[b/]	Per acre treatment cost[c/]	Total cost[d/]	Per acre yield	Total production[e/]	Value per cwt	Total value[f/]	Total value less treatment costs	Loss with best alternative[g/]
	---Thousands---		Dollars	Thousand Dollars	CWT	Thousand CWT	Dollars	---------Thousand Dollars---------		
Mississippi:										
2,4,5-T	142	99	9.50	941	40.3[a/]	3,989.7	8.11[k/]	32,356	31,415	
Silvex, 2,4-D & propanil	142	99	N.A.	1,175	N.A.	3,815.7		30,814	29,639	1,776
Silvex		30	9.50	285	40.3[a/]	1,209.0	8.11[k/]	9,805		
2,4-D		0	----	----	----	----	----	----		
Propanil		69	12.90	890	38.3[i/]	2,642.7	7.95[m/]	21,009		
2,4-D & propanil	142	99	N.A.	1,167	N.A.	3,815.7	N.A.	30,398	29,231	2,184
2,4-D		20	7.40	148	39.5[h/]	790.0	8.03[l/]	6,344		
Propanil		79	12.90	1,019	39.3[i/]	3,025.7	7.95[m/]	24,054		
2,4-D	142	99	N.A.	148	N.A.	3,562.9	N.A.	27,945	27,797	
2,4-D		20	7.40	148	39.5[h/]	790.0	8.03[l/]	6,344		
No Treatment		79	0.00	0	35.1[j/]	2,772.9	7.79[n/]	21,601		
Propanil	142	99	12.90	1,277	38.3[i/]	3,791.7	7.95[m/]	30,144	28,867	
No Treatment	142	99	0.00	0	35.1[j/]	3,474.9	7.79[n/]	27,069	27,069	
Louisiana:										
2,4,5-T	62	17	9.50	162	38.0[a/]	646.0	8.03[k/]	5,187	5,025	

continued

Table 16--Annual use and returns for 2,4,5-T and projected returns with alternative scenarios 1-3 years after 2,4,5-T becomes unavailable, rice-growing areas of Arkansas, Mississippi, Louisiana, and Missouri (Continued)

Area & alternative treatment	Acres in area[a]	Treated acres[b]	Per acre treatment cost[c]	Total cost[d]	Per acre yield	Total production[e]	Value per cwt	Total value[f]	Total value less treatment costs	Loss with best alternative[g]
	----Thousands----		Dollars	Thousand Dollars	CWT	Thousand CWT	Dollars	----------Thousand Dollars----------		
Silvex, 2,4-D & propanil	62	17	N.A.	203	N.A.	623.2	N.A.	4,935	4,732	293
Silvex		5	9.50	48	38.0[a]	190.0	8.03[k]	1,526		
2,4-D		0	----	----	----	----	----	----		
Propanil		12	12.90	155	36.1[i]	433.2	7.87[m]	3,409		
2,4-D & propanil	62	17	N.A.	203	N.A.	617.0	N.A.	4,864	4,661	364
2,4-D		3	7.40	22	37.2[h]	111.6	7.95[l]	887		
Propanil		14	12.90	181	36.1[i]	505.4	7.87[m]	3,997		
2,4-D	62	17	N.A.	22	N.A.	575.0	N.A.	4,460	4,438	
2,4-D		3	7.40	22	37.2[h]	111.6	7.95[l]	887		
No Treatment		14	0.00	0	33.1[j]	463.4	7.71[n]	3,573		
Propanil	62	17	12.90	219	36.1[i]	613.7	7.87[m]	4,830	4,611	
No Treatment	62	17	0.00	0	33.1[j]	562.7	7.71[n]	4,338	4,338	
Missouri:										
2,4,5-T	16	4	9.50	38	41.1[a]	164.4	8.44[k]	1,388	1,350	
Silvex, 2,4-D & propanil	16	4	N.A.	49	N.A.	158.1	N.A.	1,315	1,266	84

continued

Table 16—Annual use and returns for 2,4,5-T and projected returns with alternative scenarios 1-3 years after 2,4,5-T becomes unavailable, rice-growing areas of Arkansas, Mississippi, Louisiana, and Missouri (Continued)

Area & alternative treatment	Acres in area[a]	Treated acres[b]	Per acre treatment cost[c]	Total cost[d]	Per acre yield	Total production[e]	Value per cwt	Total value[f]	Total value less treatment costs	Loss with best alternative[g]
	---Thousands---		Dollars	Thousand Dollars	CWT	Thousand CWT	Dollars	---------Thousand Dollars---------		
Silvex		1	9.50	10	41.1[a]	41.1	8.44[k]	347		
2,4-D		0	----	----	----	----	----	----		
Propanil		3	12.90	39	39.0[i]	117.0	8.28[m]	968		
2,4-D & propanil	16	4	N.A.	46	N.A.	157.3	N.A.	1,305	1,259	91
2,4-D		1	7.40	7	40.3[h]	40.3	8.36[l]	337		
Propanil		3	12.90	39	39.0[i]	117.0	8.27[m]	968		
2,4-D	16	4	N.A.	7	N.A.	147.7	N.A.	1,207	1,200	
2,4-D		1	7.40	7	40.3[h]	40.3	8.36[l]	337		
No Treatment		3	0.00	0	35.8[j]	107.4	8.10[n]	870		
Propanil	16	4	12.90	52	39.0[i]	156.0	8.27[m]	1,290	1,238	
No Treatment	16	4	0.00	0	35.8[j]	143.2	8.10[n]	1,160	1,160	
Totals, 4 States:										
2,4,5-T	1,075	292	9.40	2,775	43.1	2,574.5	8.26	103,925	101,150	
Silvex, 2,4-D & propanil	1,075	292	10.65	3,112	41.9	12,234.8	8.18	100,102	96,990	4,160
Silvex		96	9.40	913	--	4,152.1	--	34,350		
2,4-D		60	7.40	444	--	2,658.0	--	22,088		
Propanil		136	12.90	1,755	--	5,424.7	--	43,664		

continued

Table 16--Annual use and returns for 2,4,5-T and projected returns with alternative scenarios 1-3 years after 2,4,5-T becomes unavailable, rice-growing areas of Arkansas, Mississippi, Louisiana, and Missouri (Continued)

Area & alternative treatment	Acres in area[a/]	Treated acres[b/]	Per acre treatment cost[c/]	Total cost[d/]	Per acre yield	Total production[e/]	Value per cwt	Total value[f/]	Total value less treatment costs	Loss with best alternative[g/]
	---Thousands-----		Dollars	Thousand Dollars	CWT	Thousand CWT	Dollars	----------Thousand Dollars---------		
2,4-D & propanil	1,075	292	10.26	2,996	41.5	12,131.2	8.14	98,792	95,796	5,354
2,4-D		140	7.40	1,035	--	6,080.7	--	50,117		
Propanil		152	12.90	1,961	--	6,050.5	--	48,675		
2,4-D	1,075	292	N.A.	1,035	39.8	11,625.2	8.07	93,833	92,798	
2,4-D		140	7.40	1,035	--	6,080.7	--	50,117		
No Treatment		152	0.00	0	--	5,544.5	--	43,716		
Propanil	1,075	292	12.90	3,767	40.9	11,940.2	8.10	96,696	92,929	
No Treatment	1,075	292	0.00	0	37.5	10,940.4	7.94	86,847	86,847	

a/ Data taken from Tables 1 and 6; average for 1975-1977.

b/ Data derived from official state records when available, from surveys, and from estimates made by professional workers in given areas. Personal communications between Roy Smith, USDA-SEA-AR, Stuttgart, AR and John B. Baker, LSU, Baton Rouge, LA, June 23, 1978; Ted Miller and Don Bowman, MSU, Stoneville, MS, June 23, 1978; Harold Kerr and Joe Scott, Delta Center, U. Missouri, Portageville, MO, June 29, 1978; Ford Eastin, Texas A&M University, Beaumont, TX, June 21, 1978; Don Seaman, U.of CA, Biggs, CA, June 20, 1978; Baldwin (1978). When silvex is substituted for 2,4,5-T, we estimate that in Arkansas 35, 35, and 30 percent of the 2,4,5-T acreage will be treated with silvex, 2,4-D and propanil, respectively. We estimate that in Mississippi, Louisiana, and Missouri 30 and 70 percent of the 2,4,5-T treated acreage will be sprayed with silvex and propanil, respectively; if silvex is available no 2,4-D will be used in Mississippi, Louisiana, and Missouri.

continued

Table 16--Annual use and returns for 2,4,5-T and projected returns with alternative scenarios 1-3 years after 2,4,5-T becomes unavailable, rice-growing areas of Arkansas, Mississippi, Louisiana, and Missouri (Continued)

c/ Data taken from table 22.

d/ Treated acres times per acre treatment cost.

e/ Treated acres times per acre yield.

f/ Total production times value per cwt.

g/ Total value less treatment costs for 2,4,5-T minus total value less treatment costs for alternative.

h/ Based on 2 percent yield loss estimated in biological assessment.

i/ Based on 5 percent yield loss estimated on biological assessment.

j/ Based on 13 percent yield loss estimated in biological assessment.

k/ Data taken from table 5.

l/ Based on 1 percent quality loss estimated in biological assessment.

m/ Based on 2 percent quality loss estimate in biological assessment.

n/ Based on 4 percent quality loss estimate in biological assessment.

SOURCE: Natural Resource Economics Division, Economics, Statistics, and Cooperatives Service, U.S. Department of Agriculture, Corvallis, Oregon.

Yield and quality losses have been estimated for hemp sesbania, northern jointvetch, ducksalad, morningglory, and redstem. These five weeds cause yield and quality losses that range from 1 to 10 percent and 0 to 4 percent, respectively (table 17).

Hemp sesbania and northern jointvetch cause yield and quality losses of 7 to 8 percent and 4 percent, respectively (table 17). Rarely do these two weeds infest entire ricefields in uniformly heavy infestations (USDA-SEA-AR 1978). They infest parts of fields in heavy stands or grow in sparse stands over entire fields. These plants produce numerous black seeds that are harvested with the rice during combining (table 11). Weed seeds, harvested with the rough rice, must be removed during the processing and milling operations. Although the seeds can be removed by special handling procedures, the grade and value is lowered because of the extra cost required for removing the seed (Howell 1977). Frequently, infestations of black seed lower the grade from U.S No. 1 to No. 4 which is a discount of $0.33 per cwt (table 12). Also, because weed plants are vegetatively green at harvest, they impede harvest operations, increase combine losses, and raise the moisture of rice (Smith et al. 1977).

Ducksalad and redstem are aquatic weeds that frequently grow in ricefields together with other less frequently occurring aquatic weeds (Smith et al. 1977). It is estimated that redstem occurs about one-half as frequently as ducksalad (table 15). Both weeds germinate as soon as ricefields are flooded. Ducksalad, a short, high-density weed, causes competition and significant yield losses during the first 4 to 8 weeks of the growing season (Smith et al. 1977). Even when ducksalad infestation reduces yield significantly, it does not reduce quality or grade of the rough rice. The plant produces tiny seeds that are not harvested with the grain during the combining of rice. Also, the plant usually dies naturally before rice matures. However, redstem, a taller less-thickly-populated weed than ducksalad, competes with rice during the late growing season and produces seed pods that interfere with combining and are harvested with the rough rice. Therefore, yield and quality of rough rice are reduced.

Table 17--Rice infested with and yield and quality losses from selected weeds in the 2,4,5-T use area when rice received no control inputs a/

Weed	Acres infested b/	Loss with no weed control inputs: Yield c/	Loss with no weed control inputs: Quality d/
	1,000 acres	Percent	Percent
Hemp sesbania	572	8	4
Northern jointvetch	518	7	4
Ducksalad	648	10	0
Morningglory	464	1	4
Redstem	324	3	2
Acres infested with one or more weeds e/	860		
Percent loss from one or more weeds f/		13	4

a/ 2,4,5-T use area includes Arkansas, Mississippi, Missouri, and northern Louisiana (1,080,000 acres) (table 3).

b/ Based on 1976 survey by Arkansas Cooperative Extension Service (1977) and on estimates by Arkansas Cooperative Extension Service (1978e) and technical personnel.

c/ Based on data in Tables 9 & 10 for hemp sesbania, northern jointvetch, and ducksalad; based on estimates by the Arkansas Cooperative Extension Service (1978e) and Baldwin (1978) for morningglory and redstem.

d/ Grade reduction from US no.1 to no.4 causes a loss of $0.33 per cwt (table 12). Avg. yield and crop value/A in 2,4,5-T use areas = 44 cwt and $366, respectively (table 3) [(44)(0.33) = $14.50 ÷ 366 = 4%].

e/ An estimated 80% of the total acres in the 2,4,5-T use area infested with all or some of the 5 weeds [(1,080,000)(0.80)].

f/ Total yield loss from one or more weeds is estimated at 13%; total quality loss from one or more weeds is estimated at 4%.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

Most species of morningglory grow on levees because they do not tolerate flooding (table 18, Smith et al. 1977). Three species grow mainly on ricefield levees. However, willowleaf morningglory tolerates floodwater; consequently it grows in flooded areas of the field. Morningglories cause only small yield losses. Because morningglories produce numerous large black weed that are harvested with the rough rice, they reduce the grade of rough rice significantly (table 11). Because these black seeds must be removed from the rough rice by costly handling operations, the grade of grain containing morningglory seed is reduced.

Because the five weed species listed in tables 17, 19, and 20 frequently grow in ricefields with other species, the loss in yield and quality would not be additive. Therefore, these five species, in addition to other broadleaf, aquatic, and sedge species usually associated with the five, cause an average estimated 13 percent reduction in yield and 4 percent loss in grade if controls are not used (table 17).

In the four states where 2,4,5-T is used, losses in yield range from $40 to $48 per acre; losses in quality range for $12 to $15 per acre (USDA-SEA-AR 1978). These losses would occur if 2,4,5-T were not available for use in weed-management programs. Without effective control programs, infestations of hemp sesbania, northern jointvetch, ducksalad, morningglory, and redstem would increase during the first 3-year cropping cycle and reductions in yield and quality woudl be prevalent (table 19). If 2,4,5-T were not available for use in the four State area and substitutes were not used, net losses of treatment costs would exceed $14 million annually (table 16).

As time progressed, losses would increase if inputs were not used to control weeds. During the second cropping cycle (4 to 6 years), yield losses and quality losses would average 16 and 5 percent, respectively (table 20).

Table 18—Effect of floodwater on growth of morningglory species grown in the greenhouse, 1975[a/]

Species of morningglory	Moist soil	Flooded at seeding (2/25)	Flooded at emergence (2/28)	Flooded 10 days after emergence (3/10)	Flooded 17 days after emergence (3/17)	Flooded 24 days after emergence (3/24)
	(gr.wt, g)	(% control — using moist soil as base)				
Tall, Ipomoea purpurea	24.2	100	60	0	0	2
Ivyleaf, I. hederacea	36.1	100	62	29	22	45
Small white, I. obscura	36.7	100	66	70	79	71
Willowleaf, I. Wrightii	16.2	100	0	0	0	0
Smallflower, Jacquemontia tannifolia	4.5	100	100	98	22	0
Small moonflower, Calonyction muricatum	74.0	100	65	42	32	26
			Leaf stage and height (inches) at indicated time of flooding			
Tall	NA[b/]	NA	1/4-1/2	2 lf, 4-5	5 lf, 10-12	5 lf, 24-28
Ivyleaf	NA	NA	do.	2 lf, 5-6	6 lf, 24-28	8-10 lf, 32-36
Small white	NA	NA	do.	2 lf, 3-4	5 lf, 8-10	6 lf, 16-18
Willowleaf	NA	NA	do.	2 lf, 2-3	4 lf, 10-12	8 lf, 24-26
Smallflower	NA	NA	do.	1 lf, 1-2	2 lf, 2-3	3 lf, 4-6
Small moonflower	NA	NA	2	2 lf, 9-10	4 lf, 20-24	6 lf, 34-36

a/ Morningglories seeded 3/4" deep in sterilized Crowley silt loam in no. 10 pots Feb. 25, 1975; emerged Feb. 28. Pots flushed to germinate weeds. Pots were flooded at indicated times to a depth of 1". Weed harvested for green weight 4/7. Stage and height (in.) of morningglory when flooded after emergence follow:

b/ Not applicable.

SOURCE: Unpublished, R. J. Smith, Jr. USDA-SEA-AR, Stuttgart, AR.

Table 19--Yield and quality losses in rice from selected weeds and weed control practices during the first 3 years after banning 2,4,5-T a/

	Weed control practice											
	None b/		2,4,5-T c/		Propanil d/		2,4-D e/		Silvex f/		Molinate g/	
Weed	Yield loss	Quality loss	Yield loss	Quality loss	Yield loss	Quality loss	Yield loss	Quality loss	Yield loss	Quality loss	Yield loss	Quality loss
	Percent loss											
Hemp sesbania	8	4	0	0	0	0	0	0	0	0	8	4
Northern jointvetch	7	4	0	0	5	3	5	2	0	0	7	4
Ducksalad	10	0	0	0	5	0	2	0	0	0	10	0
Morningglory	1	4	0	0	1	4	0	0	0	0	1	4
Redstem	3	2	0	0	2	2	1	1	0	0	3	2
Average h/	13	4	0	0	5	2	2	1	0	0	13	4

a/ All estimates by the Arkansas Cooperative Extension Service (1978e), Baldwin (1978), and USDA-SEA-AR (1978). Rice grown on land one year out of three; soybeans grown two years.

b/ Data from table 17. Do nothing.

c/ 2,4,5-T gives sufficient control to prevent losses on the 292,000 acres treated.

d/ Propanil can be used in the entire 2,4,5-T use area. It controls hemp sesbania as well as 2,4,5-T; it is partially effective on northern jointvetch, ducksalad, and redstem; it is ineffective on morningglory.

e/ Efficacy on treated acres — 2,4-D can be used on about 50% of the 2,4,5-T use acreage in Arkansas and on only about 20% of the 2,4,5-T use acreage in Mississippi, Louisiana, and Missouri. It controls hemp sesbania, ducksalad, morningglory, and redstem as well as 2,4,5-T, but cannot be applied early to prevent competition and losses from ducksalad and redstem; it is only partially effective on northern jointvetch (table 4).

f/ Use in 2,4,5-T area — Silvex can be used on about 50% of the 2,4,5-T use acreage in Arkansas, Mississippi, Louisiana, and Missouri. It controls all weeds about as well as 2,4,5-T, but its spray drift is more injurious than 2,4,5-T to cotton and soybeans (table 4; Smith et al, 1977, p. 15). Also, effective formulations of silvex are low volatility esters which are more active and more volatile in high temperature (95°F) ricefield environments than amine salts of 2,4,5-T (Smith et al 1977 p. 15).

g/ Although molinate can be used in all 2,4,5-T use areas, it is ineffective on the broadleaf weeds (table 4).

h/ Estimated average loss from one or more weeds; this value is not a numerical average.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

Table 20—Yield and quality losses in rice from selected weeds and weed control practices during the 4 to 6 year period after banning 2,4,5-T a/

Weed	None b/		2,4,5-T c/		Propanil d/		2,4-D e/		Silvex f/	
	Yield loss	Quality loss	Yield loss	Quality loss	Yield loss	Quality loss	Yield loss	Quality loss	Yield loss	Quality loss
	Percent									
Hemp sesbania	12	5	0	0	0	0	0	0	0	0
Northern jointvetch	10	5	0	0	8	4	8	4	0	0
Ducksalad	12	0	0	0	8	0	4	0	0	0
Morningglory	2	6	0	0	2	6	0	0	0	0
Redstem	5	3	0	0	4	3	2	1	0	0
Average g/	16	5	0	0	8	3	4	2	0	0

a/ All estimates by USDA-SEA-AR (1978) and the Arkansas Cooperative Extension Service, (1978e) and Baldwin (1978). Rice grown on land one year out of three; soybeans grown two years.

b/ Do nothing; uncontrolled weed infestations build-up during the second 3-year cycle.

c/ 2,4,5-T gives sufficient control to prevent losses on 292,000 acres treated.

d/ Propanil controls hemp sesbania as well as 2,4,5-T; it is partially effective on northern jointvetch, ducksalad, and redstem; it is ineffective on morningglory (table 4).

e/ 2,4-D controls hemp sesbania, ducksalad, morningglory, and redstem as well as 2,4,5-T but cannot be applied early to prevent competition and losses from ducksalad and redstem (table 4).

f/ Silvex controls all weeds as effectively as 2,4,5-T but cannot be used as extensively as 2,4,5-T (see table 19, footnote f for details).

g/ Estimated average loss from one or more weeds; this value is not a numerical average.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

Water Management in Ricefields Treated with 2,4,5-T

For control of all weed species during the early growing season (3 to 6 weeks after rice emergence) the floodwater is usually drained to expose weeds to the herbicide spray (Smith et al. 1977). Flooding may begin 1 day after 2,4,5-T application and usually is completed within 10 days. Thereafter, the water usually remains on the field until the rice is almost mature.

At midseason, (when rice internodes are 0.25 to 0.5 inch long), the floodwater is drained when short weed species, e.g. ducksalad, redstem, or waterhyssop infest the field (Smith et al. 1977). The soil may be muddy or dry, depending on how long the field was drained before application. If tall weeds, e.g. hemp sesbania, northern jointvetch, or gooseweed infest the field, the floodwater usually remains on the field for midseason application. However, the flood depth is shallow (about 2 inches deep) to expose as much weed growth as possible. After the midseason application, the floodwater remains on the field until the crop matures, (usually 40 to 45 days, table 14). Because the rate of development of rice varieties differs, 2,4,5-T is applied at different times after crop emergence (table 14). However, the period between 2,4,5-T applications at midseason and draining floodwater at maturity for all varieties is almost the same (40 to 45 days).

Source of Water For Rice Irrigation

Sources of water for ricefield irrigation include shallow and deep wells, reservoirs, rivers, bayous, lakes, and drainways (USDA-ARS 1978). In Arkansas, main sources of water include shallow (70 to 150 feet) and deep (600 to 800 feet) wells, reservoirs, and bayous. In northeast Louisiana and Mississippi, most of the irrigation water comes from shallow wells (70 to 150 feet) and bayous.

For successful rice production, it is important that the available water be of suitable quality. Rice irrigation water should be free of dissolved salts that are toxic to rice plants. Generally water is considered satisfactory for irrigating if it contains less than 400 pounds per acre-ft. of calcium carbonate equivalent and a conductivity measurement (EC x 10^6) of less than 900 (Huey 1977).

Chemical Alternatives

Patterns Of Use

Propanil

Propanil, applied to emerged rice and weeds, selectively kills barnyardgrass and many other grass, aquatic, broadleaf, and sedge weeds while rice is only slightly injured (table 4). About 79 percent of the rice in the U.S. is treated with propanil (table 1). Only a small acreage in California is treated with this herbicide because of restrictions on its use in the Sacramento Valley rice-producing area where spray drift from ricefields severely damages prune trees. However, propanil is used extensively in the southern rice-producing area, with about 95 percent of the rice acreage treated each year (table 1).

Propanil is usually applied aerially twice during the early growing season for control of grasses (Smith et al. 1977). Rates used range from 2 to 5 lb/A for each application—not to exceed a rate of 8 lb/A total per season. This is the maximum labeled amount that can be applied to the rice crop each year. Frequently, the maximum rate of 8 lb/A in two applications is required to control grass weeds (Gerlow 1973). Therefore, the control of the total weed population in the ricefield requires additional applications of other types of herbicides--the phenoxy herbicide group. Thus, a significant amount of rice acreage in the South is treated with phenoxy herbicides; the principal one used in Arkansas, Mississippi, northern Louisiana, and Missouri is 2,4,5-T (table 1).

If 2,4,5-T were not available to control weeds, propanil applications would need to exceed the maximum registered rate to obtain control of the grass and broadleaf weed complex. Such a practice could cause problems of rice injury and possible residues in the grain that exceed established tolerances for propanil.

Although propanil injures nontarget crops less than 2,4,5-T or other phenoxy herbicides, it can drift and injure crops such as cotton and soybeans (Smith et al. 1977). Precautions must be used when applying propanil to prevent damage to nontarget crops. Also, propanil injures rice when applied after midseason (when the internodes are more than 0.5 inches long). Therefore, timely applications are required to control weeds without causing severe damage to rice.

2,4-D

This herbicide is used each year on about 332,000 acres of rice in the U.S. (table 1). It is used in the southern rice-producing areas, but not in California. The acreage treated in the South ranges from 30 percent in Louisiana to little, if any, in Missouri. It is applied for control of many broadleaf, aquatic, and sedge weeds (table 4). It would be used more frequently if it were not so injurious to cotton (Smith et al. 1977, p. 15). Spray from aerial applications to ricefields frequently drifts to nearby cotton fields to cause significant damage. Most rice-growing states regulate the application of 2,4-D to ricefields.

Water soluble liquid amines and inorganic or organic salt powders are used to control weeds in rice (Smith et al. 1977). Rates of 2,4-D used for weed control in rice range from 0.5 to 1.5 lb/A of acid equivalent.

The rate depends on weed species, air and water temperatures, and other factors.

The stage of rice growth is very critical when 2,4-D is applied to rice (Smith et al. 1977). The rice must be in the early jointing stage (internodes 1/8 - 1/2 inch long); the time required for rice to reach the tolerant stage of growth varies with variety. Rice treated with 2,4-D during the early tillering stage (before the internodes begin elongating) grows tubular leaves ("onion leaf" symptoms) and malformed panicles. Also, rice treated with 2,4-D during the booting and panicle development stages may be injured severely. Rice treated during susceptible stages of growth may be reduced in yield by as much as 27 percent (Smith et al. 1977). It also can reduce plant height and bushel weight.

The floodwater is usually drained or lowered to expose weed growth to 2,4-D spray (Smith et al. 1977). Soon after application the floodwater is reapplied or increased to normal depths.

2,4-D is applied with low gallonage sprayers mounted on fixed-wing or helicopter aircraft in the same way 2,4,5-T is applied (Smith et al. 1977).

If 2,4,5-T were unavailable for use in rice, 2,4-D would be substituted on some of the rice where 2,4,5-T is now used (USDA-SEA-AR 1978). The amount of acreage treated with 2,4-D would vary somewhat with the rice-producing area. In Arkansas, 2,4-D could be used on all of the rice now treated with 2,4,5-T in the prairie-growing area; in other rice-growing areas of Arkansas 2,4-D could be substituted for 2,4,5-T on about half the acreage. However, in the Mississippi, Louisiana, and Missouri rice-producing areas, 2,4-D would be substituted for 2,4,5-T on only about 20 percent of the acreage. In the Mississippi River Delta areas where cotton is grown extensively, 2,4-D could not be used because of possible drift and damage to cotton.

One problem with the use of 2,4-D is that it cannot be applied during the early season; therefore, early competition of weeds such as ducksalad would have already occurred before this herbicide could be applied.

Silvex

This herbicide, which is applied aerially in the same way as 2,4-D, is used on less than 1 percent of the rice in the U.S. (table 1). It is used occasionally in the southern rice-producing area and not at all in California. It is applied for control of many broadleaf, aquatic, and sedge weeds (table 4). It has almost comparable activity to 2,4,5-T on most broadleaf, aquatic, and sedge weeds (table 4). This herbicide is very injurious to soybeans, a rotation crop with rice, and is more damaging to cotton than 2,4,5-T (Smith et al. 1977).

Emulsifiable ester formulations are used for weed control in rice (Smith et al. 1977). The amine and inorganic, salt formulations of silvex do not control the broadleaf, aquatic, and sedge weed complex of ricefields (USDA-SEA-AR 1978). Also, low-volatile ester formulations may vaporize in the hot (90°F or above) ricefield environment after application (Smith et al. 1977, Downey and Wells 1975). Vapor drift from ricefields to soybeans or cotton could damage these susceptible crops.

Rates, volumes and stages of rice growth for applying silvex are the same as for 2,4,5-T (Smith et al. 1977). Water management and other application and production practices for silvex and 2,4,5-T are the same.

If 2,4,5-T were not available for use in rice, silvex would be substituted on some of the rice where 2,4,5-T is now used (table 16) (USDA-SEA-AR 1978). The amount of acreage treated with silvex would be about the same in all 2,4,5-T use areas, which we estimate to be about 30-35 percent of the 2,4,5-T treated acreage. However, it would be used in a combined weed-control program with propanil and/or 2,4-D.

Propanil And/Or 2,4-D

If 2,4,5-T were unavailable for use in rice, propanil and/or 2,4-D would be viable substitutes for 2,4,5-T on most of the rice now being treated with 2,4,5-T (tables 16 and 21). The particular pattern of use would entail applications of 2,4-D on rice where it could be used safely. These rice-producing areas would include all of the prairie and about 50 percent of the acreage in other rice-producing areas of Arkansas. Also, 2,4-D could be used on about 20 percent of the rice now being treated with 2,4,5-T in Mississippi, Louisiana, and Missouri. Where 2,4-D could not be used safely, propanil alone would be used on the remainder of the acreage presently being treated with 2,4,5-T. Therefore, each herbicide (2,4-D and propanil) would be used on about 50 percent of the rice presently being treated with 2,4,5-T (tables 16 and 21). The substitution propanil treatment for 2,4,5-T would be in addition to earlier propanil treatments for grass control.

2,4-D would be used where applications could be made safely (from the standpoints of spray drift to cotton and safety to rice) because it controls many broadleaf, aquatic, and sedge weeds better than propanil (USDA-SEA-AR 1978). Propanil would be used during the early season when 2,4-D injures rice. It would also be used in all areas where cotton is grown near rice and where 2,4-D would be too hazardous or would be illegal.

Problems that would be encountered with the use of propanil and 2,4-D substituted for 2,4,5-T include: (a) the maximum registered rate of propanil may have to be exceeded to control the grass and broadleaf weed complex, (b) because early applications of 2,4-D injures rice, significant weed competition and losses would occur before the herbicide can be applied safely at midseason, and (c) propanil and 2,4-D do not control the weed complex as effectively as 2,4,5-T.

Silvex or 2,4-D with Propanil

If 2,4,5-T were unavailable for use in rice, the best substitute for 2,4,5-T would be silvex or 2,4-D with propanil on most of the

Table 21--Annual use and returns for 2,4,5-T and projected returns with alternative scenarios 4-6 years after 2,4,5-T becomes unavailable--rice growing areas of Arkansas, Mississippi, Louisiana and Missouri

Area & alternative treatment	Acres in area[a]	Treated acres[b]	Per acre treatment cost[c]	Total cost[d]	Per acre yield	Total production[e]	Value per cwt	Total value[f]	Total value less treatment costs	Loss with best alternative[g]
	---Thousands---		Dollars	Thousand Dollars	CWT	Thousand CWT	Dollars	---Thousand Dollars---		
Arkansas:										
2,4,5-T	855	172	9.50	1,634	45.2[a]	7,774.4	8.36[j]	64,994	63,360	
Silvex, 2,4-D & propanil	855	172	N.A.	1,685	N.A.	7,479.2	N.A.	61,543	59,858	3,502
Silvex		60	9.50	570	45.2[a]	2,712.0	8.36[j]	22,672		
2,4-D		60	7.40	444	43.4[h]	2,604.0	9.19[k]	21,327		
Propanil		52	12.90	671	41.6[i]	2,163.2	8.11[l]	17,544		
2,4-D & propanil	855	172	N.A.	1,580	N.A.	7,364.0	N.A.	60,125	58,545	4,815
2,4-D		116	7.40	858	43.4[h]	5,034.4	8.19[k]	41,232		
Propanil		56	12.90	722	41.6[i]	2,329.6	8.11[l]	18,893		
Mississippi:										
2,4,5-T	142	99	9.50	941	40.3[a]	3,989.7	8.11[j]	32,356	31,415	
Silvex, 2,4-D & propanil	142	99	N.A.	1,175	N.A.	3,768.9	N.A.	29,951	28,776	2,639
Silvex		30	9.50	285	40.3[a]	1,209.0	8.11[j]	9,805		
2,4-D		0	----	----	----	----	----	----		
Propanil		69	12.90	890	37.1[i]	2,559.9	7.87[l]	20,146		

continued

Table 21--Annual use and returns for 2,4,5-T and projected returns with alternative scenarios 4-6 years after 2,4,5-T becomes unavailable—rice growing areas of Arkansas, Mississippi, Louisiana and Missouri (Continued)

Area & alternative treatment	Acres in area[a]	Treated acres[b]	Per acre treatment cost[c]	Total cost[d]	Per acre yield	Total production[e]	Value per cwt	Total value[f]	Total value less treatment costs	Loss with best alternative[g]
	—Thousands—		Dollars	Thousand Dollars	CWT	Thousand CWT	Dollars	—Thousand Dollars—		
2,4-D & propanil	142	99	N.A.	1,167	N.A.	3,704.9	N.A.	29,219	28,052	3,363
2,4-D		20	7.40	148	38.7[h]	774.0	7.95[k]	6,153		
Propanil		79	12.90	1,019	37.1[i]	2,930.9	7.87[l]	23,066		
Louisiana:										
2,4,5-T	62	17	9.50	162	38.0[g]	646.0	8.03[j]	5,187	5,025	
Silvex, 2,4-D & propanil	62	17	N.A.	203	N.A.	610.0	N.A.	4,798	4,595	430
Silvex		5	9.50	48	38.0[g]	190.0	8.03[k]	1,526		
2,4-D		0	----	----	----	----	----	----		
Propanil		12	12.90	155	35.0[i]	420.0	7.79[l]	3,272		
2,4-D & propanil	62	17	N.A.	203	N.A.	599.5	N.A.	4,679	4,476	549
2,4-D		3	7.40	22	36.5[h]	109.5	7.87[k]	862		
Propanil		14	12.90	181	35.0[i]	490.0	7.79[l]	3,817		
Missouri:										
2,4,5-T	16	4	9.50	38	41.1[g]	164.4	8.44[j]	1,388	1,350	
Silvex, 2,4-D & propanil	16	4	N.A.	49	N.A.	154.5	N.A.	1,276	1,227	123
Silvex		1	9.50	10	41.1[g]	41.1	8.44[j]	347		

continued

Table 21--Annual use and returns for 2,4,5-T and projected returns with alternative scenarios 4-6 years after 2,4,5-T becomes unavailable--rice growing areas of Arkansas, Mississippi, Louisiana and Missouri (Continued)

Area & alternative treatment	Acres in area[a]	Treated acres[b]	Per acre treatment cost[c]	Total cost[d]	Per acre yield	Total production[e]	Value per cwt	Total value[f]	Total value less treatment costs	Loss with best alternative[g]
	---Thousands---		Dollars	Thousand Dollars	CWT	Thousand CWT	Dollars	---Thousand Dollars---		
2,4-D		0	----	----	----	----	----	----		
Propanil		3	12.90	39	37.8[i]	113.4	8.19[l]	929		
2,4-D & propanil	16	4	N.A.	46	N.A.	152.9	N.A.	1,256	1,210	140
2,4-D		1	7.40	7	39.5[h]	39.5	8.27[k]	327		
Propanil		3	12.90	39	37.8[i]	113.5	8.19[l]	929		
Totals, 4 states:										
2,4,5-T	1,075	292	9.50	2,775	43.1	12,574.5	8.26	103,925	101,150	
Silvex, 2,4-D & propanil	1,075	292	10.66	3,112	41.1	12,012.6	8.12	97,568	94,456	6,694
Silvex		96	9.50	913	----	4,152.1		34,350		
2,4-D		60	7.40	444	----	2,604.0		21,327		
Propanil		136	12.90	1,755	----	5,256.5		41,891		
2,4-D & propanil	1,075	292	10.26	2,996	40.5	11,821.3	8.06	95,279	92,283	8,867
2,4-D		140	7.40	1,035	42.6	5,957.4	8.15	48,574		
Propanil		152	12.90	1,961	38.6	5,863.9	7.96	46,705		

a/ Data taken from Tables 1 and 6; average for 1975-1977.

continued

Table 21--Annual use and returns for 2,4,5-T and projected returns with alternative scenarios 4-6 years after 2,4,5-T becomes unavailable--rice growing areas of Arkansas, Mississippi, Louisiana and Missouri (Continued)

b/ Data derived from official state records when available, from surveys, and from estimates made by professional workers in given areas. Personal communications between Roy Smith, USDA-SEA-AR, Stuttgart, AR and John B. Baker, LSU, Baton Rouge, LA, June 23, 1978; Ted Miller and Don Bowman, MSU, Stoneville, MS, June 23, 1978; Harold Kerr and Joe Scott, Delta Center, U. Missouri, Portageville, MO, June 19, 1978; Ford Eastin, Texas A&M University, Beaumont, TX, June 21, 1978; Don Seaman, U. of CA, Biggs, CA, June 20, 1978; Baldwin (1978). When silvex is substituted for 2,4,5-T, we estimate that in Arkansas 35, 35, and 30 percent of the 2,4,5-T treated acreage will be treated with silvex, 2,4-D, and propanil, respectively; we estimate that in Mississippi, Louisiana, and Missouri 30 and 70 percent of the 2,4,5-T treated acreage will be sprayed with silvex and propanil, respectively; if silvex is available no 2,4-D will be used in Mississippi, Louisiana, and Missouri.

c/ Data taken from Table 22.

d/ Treated acres times per acre treatment cost.

e/ Treated acres times per acre yield.

f/ Total production times value per cwt.

g Total value less treatment costs for 2,4,5-T minus total value less treatment costs for alternative.

h/ Based of 4 percent yield loss estimated in biological assessment.

i/ Based on 8 percent yield loss estimated in biological assessment.

j/ Data taken from Table 5.

k/ Based on 2 percent quality loss estimated in biological assessment.

l/ Based on 3 percent quality loss estimated in biological assessment.

SOURCE: Natural Resource Economics Division, Economics, Statistics, and Cooperatives Service, U.S. Department of Agriculture, Corvallis, Oregon.

rice now being treated with 2,4,5-T (table 16). The pattern of use would be applications of silvex (ester) on rice where it could be used safely. Silvex would be used on about 35 percent of the 2,4,5-T treated acreage in Arkansas, mainly in the Mississippi River Delta area where cotton is intercropped with rice; it would be used on about 30 percent of the 2,4,5-T treated acreage in Mississippi, Louisiana, and Missouri, especially where cotton is intercropped with rice. Also, silvex would be used in all of these areas where early-season applications are required to control early infestations of broadleaf, aquatic, and sedge weeds. About 35 percent of the rice in Arkansas would be treated with 2,4-D; it would be used principally in the prairie rice-producing areas where cotton is not grown and where soybeans, which are highly susceptible to silvex, is intercropped with rice. 2,4-D would not be used in the 2,4,5-T use areas of Mississippi, Louisiana, and Missouri because cotton, which is highly susceptible to 2,4-D, is grown near rice. Where silvex or 2,4-D could not be used, propanil would be used on the remainder of the acreage presently being treated with 2,4,5-T; we estimate that propanil would be used for broadleaf weed control on about 30 percent of the 2,4,5-T acreage in Arkansas and about 70 percent of the acreage in Mississippi, Louisiana, and Missouri.

Problems that would be encountered with the use of silvex, 2,4-D and propanil substituted for 2,4,5-T include: (a) only the ester formulations of silvex, which are somewhat volatile in the high temperature (90°F +) ricefield environment, control weeds of rice effectively, (b) silvex, which is significantly more injurious than 2,4,5-T to nontarget soybeans and cotton, would be used in fewer weed control situations than 2,4,5-T, and (c) the maximum registered rate of propanil may have to be amended to control the grass and broadleaf weed complex.

Other Herbicides

Molinate, which is used on about 47 percent of the rice in the U.S., is not a substitute for 2,4,5-T (tables 4 and 19). Molinate does not control the principal broadleaf and aquatic weeds that are troublesome in the 2,4,5-T use areas (table 19). It is ineffective on hemp sesbania, northern jointvetch, ducksalad, morningglory, and redstem.

MCPA, which is used principally in Texas and California (table 1), is less effective on many broadleaf weeds of rice (Smith et al. 1977). MCPA is not used in the 2,4,5-T use areas of Arkansas, Mississippi, northern Louisiana, and Missouri because it is relatively ineffective on hemp sesbania, northern jointvetch, and Indian jointvetch (table 4).

Bifenox, bentazon, and oxadiazon are three new herbicides that have only recently been registered for use in rice (Arkansas Cooperative Extension Service 1978e). However, they are now used on less than 2 percent of the rice in the 2,4,5-T use areas (table 1). Bifenox and oxadiazon are applied during the early season for control of barnyardgrass, sprangletop, and the aquatic-weed complex. Bentazon is applied during the early to midseason stages of growth for the control of redstem, dayflower, smartweed, and umbrellasedges. Oxadiazon and bentazon are frequently mixed with propanil for early postemergence control of weeds. The mixtures control more species of weeds than a single herbicide application.

The use of these three herbicides as substitutes for 2,4,5-T is limited because they do not control most of the broadleaf and aquatic weeds as effectively as 2,4,5-T (table 4). Bifenox and oxadiazon control ducksalad and redstem effectively, but they are only partially effective on hemp sesbania, northern jointvetch, and morningglory. Bentazon controls redstem effectively, gives partial control of ducksalad, and is ineffective on hemp sesbania, northern jointvetch, and morningglory.

Therefore, when these new herbicides are extensively used in rice, they would have only a slight impact on the use of 2,4,5-T for early and midseason control of broadleaf, aquatic, and sedge weeds in rice (USDA-SEA-AR 1978).

Potential Efficacy

Propanil

Propanil is used mainly to control grass weeds in rice. These include barnyardgrass, broadleaf signalgrass, and panicum grasses (table 4). Propanil also controls some broadleaf weeds as effectively as 2,4,5-T; these include eclipta, hemp sesbania, and waterhyssop. However, propanil is significantly less active than 2,4,5-T on many broadleaf, aquatic, and sedge weeds; these include arrowhead, beakrush, burhead, cattail, cocklebur, dayflower, gooseweed, northern and Indian jointvetch, Mexicanweed, morningglory, pondweed, redstem, smartweed, and waterprimrose.

2,4-D

This herbicide is used to control broadleaf, aquatic, and sedge weeds in rice (table 4). It is ineffective on grass weeds. 2,4-D gives excellent control of beakrush, roughseed bulrush, burhead, cocklebur, dayflower, ducksalad, eclipta, false pimpernel, fimbristylis, hemp sesbania, horned pondweed, morningglory, redstem, spikerush, and waterhyssop. It is less effective than 2,4,5-T on gooseweed, northern and Indian jointvetch, Mexicanweed, smartweed, and waterprimrose. 2,4-D is more effective than 2,4,5-T on alligatorweed, ducksalad, and horned pondweed. Therefore, 2,4-D is less effective than 2,4,5-T on 6 weed species, and is more effective on 3 species. They are about equally effective on the other weeds above.

On the 5 major broadleaf and aquatic weeds in the 2,4,5-T use area (tables 19 and 20), 2,4-D is less active than 2,4,5-T on northern jointvetch, more active on ducksalad, and about equal to 2,4,5-T on hemp sesbania, morningglory, and redstem. However, 2,4-D cannot be applied during the early season to control weeds such as ducksalad and redstem (Smith et al. 1977). Ducksalad competition reduces rice yields during the first few weeks after the crop emerges (table 10). Therefore, losses from ducksalad competition would occur before 2,4-D could be applied to the ricefield at midseason.

Propanil And 2,4-D

If both of these herbicides were substituted for 2,4,5-T, they would control weeds better than either used alone. In areas where 2,4-D could be used safely, 2,4-D would give comparable control to 2,4,5-T on hemp sesbania and morningglory; it would be less effective on northern jointvetch, ducksalad and redstem (table 19). In areas where 2,4-D could not be used, propanil would be substituted for 2,4,5-T (USDA-SEA-AR 1978). In these areas propanil controls hemp sesbania as effectively as 2,4,5-T; it gives partial control of northern jointvetch, ducksalad, and redstem; it does not control morningglory which causes more losses from dockage than any weed in the 2,4,5-T use areas of the Mississippi Valley (table 11).

Silvex, 2,4-D And Propanil

If all three of these herbicides were substituted for 2,4,5-T, they would control weeds better than any other alternative to 2,4,5-T. In areas where silvex could be used safely, it would give comparable control to 2,4,5-T on weeds, e.g., hemp sesbania, northern jointvetch, ducksalad, morningglory, and redstem (table 19). Silvex controls most of the weeds listed in table 4 almost as effectively as 2,4,5-T; however, gooseweed, northern jointvetch, Indian jointvetch, Mexicanweed, redstem, smartweed, spikerush, and waterprimrose are controlled slightly less effectively with silvex. The differentials in activity of these two herbicides on these weeds are only slight and would not contribute significantly to increased losses if silvex were substituted for 2,4,5-T.

In areas where 2,4-D could be used safely, it would give comparable control to 2,4,5-T on hemp sesbania and morningglory, but would be less effective on northern jointvetch, ducksalad, and redstem. In areas where silvex or 2,4-D could not be used safely, propanil would be used (USDA-SEA-AR 1978). In these areas propanil controls hemp sesbania as well as 2,4,5-T, it gives partial control of northern jointvetch, ducksalad, and redstem, and it does not control morningglory.

If 2,4,5-T were not available for use in rice, the best weed control would be obtained by combining the use of silvex, 2,4-D and propanil. By doing this, losses in yield and quality could be kept to a minimum. However, even with the use of silvex, 2,4-D and propanil, losses from weeds would be increased substantially when compared with 2,4,5-T (table 16).

Other Herbicides

Molinate does not control the troublesome broadleaf and aquatic weeds that infest rice (table 19). MCPA does not control troublesome leguminous broadleaf weeds (table 4). Bifenox, bentazon, and oxadiazon are only partially effective on the complexes of broadleaf, aquatic, and sedge weeds that infest rice. Therefore, none of these herbicides are effective substitutes for 2,4,5-T.

Effect on Rice Yield and Quality

Propanil

If propanil were substituted for 2,4,5-T on all the acres presently treated with 2,4,5-T, yield and quality losses would average 5 percent and 2 percent, respectively, more than they do now with the use of 2,4,5-T during the first 3-year period after banning 2,4,5-T (table 19). During the second 3-year period after banning 2,4,5-T, losses in yield and quality would average 8 percent and 3 percent, respectively (table 20). Because propanil controls hemp sesbania as effectively as 2,4,5-T, this weed would not cause any losses. Northern jointvetch, ducksalad, and redstem are only partially controlled with propanil; hence, these weeds would increase after 3 years and would cause even greater losses.

However, these losses would be less with the use of propanil than if no controls were used. Since morningglories are not controlled with propanil, they cause losses equal to no controls at all.

2,4-D

If 2,4-D were substituted for 2,4,5-T on all the rice where 2,4,5-T is presently used, yield and quality losses would average 2 percent and 1 percent, respectively more than they do now with 2,4,5-T during the first 3-year cropping cycle (table 19). During the second 3-year period, yield and quality losses would average 4 percent and 2 percent, respectively (table 20). The use of 2,4-D would prevent any losses from hemp sesbania and morningglory; however, losses would occur from northern jointvetch which is only partially controlled by 2,4-D and from ducksalad and redstem because 2,4-D cannot be applied safely to rice during the early growth stages. Because of drift hazards to cotton, and by regulatory restrictions, 2,4-D could be used on only half the present acreage treated with 2,4,5-T (USDA-SEA-AR 1978).

Silvex

Because silvex controls the principal broadleaf weeds of rice as effectively as 2,4,5-T, losses from hemp sesbania, northern jointvetch, ducksalad, and redstem would not occur on rice treated with silvex substituted for 2,4,5-T (tables 19 and 20).

Other Herbicides

Molinate fails to control the weeds listed in table 19. Therefore, losses from these weeds would be as great as if no controls were used. Because MCPA fails to control hemp sesbania and northern jointvetch, it would not be a substitute for 2,4,5-T. The new herbicides--bifenox, bentazon, and oxadiazon--would partially reduce the broadleaf-aquatic weed complex listed in table 19, but they would be substantially less effective than 2,4,5-T. Because these herbicides are so new and they are registered for use in only a few rice-producing areas, no estimates were developed as to their effectiveness in reducing losses in yield and quality of rice.

Costs

Propanil

One application of propanil costs $3.40 per acre more than one application of 2,4,5-T (table 22). Propanil applied at midseason (6-8 weeks after emergence of the crop) controls some broadleaf weeds, e.g. hemp sesbania, as effectively as 2,4,5-T. However, other weeds, e.g. northern jointvetch and morningglory are not controlled as effectively with propanil as with 2,4,5-T. If propanil were substituted for 2,4,5-T in all the rice presently treated with 2,4,5-T, rice farmers would have to spend about $1 million more for the herbicide (table 16). In addition to the extra cost for herbicides, rice farmers would encounter greater yield and quality losses because propanil gives less effective weed control than 2,4,5-T; these losses would amount to about $7.5 million annually (table 16). Therefore, the extra cost of propanil and greater losses in yield and quality, compared with 2,4,5-T, would cost rice farmers more than $8.5 million each year. Also, losses would increase with time because infestations of tolerant weeds would become more prevalent (tables 19 and 20).

2,4-D

An application of 2,4-D costs about $2 per acre less than 2,4,5-T (table 22). 2,4-D applied at midseason (rice internodes 1/8-1/2 inch long) controls many broadleaf weeds as effectively as 2,4,5-T; these include hemp sesbania and morningglory (table 19). However, 2,4-D does not control northern jointvetch, ducksalad, and redstem as effectively as 2,4,5-T. If 2,4-D were substituted for 2,4,5-T in areas where it could be used safely, it would be used on only about half of the rice now treated with 2,4,5-T alone (table 16). If no other herbicides were

Table 22--Estimated cost of using 2,4,5-T and alternate herbicides in rice areas, southern rice producing area, 1975-1977

		Herbicide								
			Propanil[a/]							
Item	Unit	2,4,5-T	One appl.	Two appl.	Molinate	2,4-D	Silvex	Bifenox	Bentazon	Oxadiazon
Quantity	lb	1.0	3.0	6.0	3.0	1.0	1.0	3.0	0.75	0.75
Cost per pound	dol	5.50	3.30	3.30	3.70	3.40	5.50	6.00	14.00	14.50
Herbicide cost/acre[b/]	dol	5.50	9.90	19.80	11.10	3.40	5.50	18.00	10.50	10.90
Application cost/acre[c/]	dol	4.00	3.00	3.00	2.75	4.00	4.00	3.00	3.00	3.00
Total herbicide cost	dol	9.50	12.90	21.80	13.85	7.40	9.50	21.00	13.50	13.90

a/ One application of 3 lb/A controls many broadleaf weeds; two applications at 3 lb/A each control weed grasses.

b/ Based on cost reported by the Arkansas Cooperative Extension Service (1978e, Baldwin (1978) and Mullins et al (1978).

c/ Based on cost reported by the Arkansas Cooperative Extension Service (1978c).

SOURCE: USDA-SEA-AR, Stuttgart, AR.

available, the other half of the acreage would receive no controls. Although rice farmers would spend about $1.7 million less for herbicides if 2,4-D were substituted for 2,4,5-T, their losses in production would be about $10.1 million more (table 16). Therefore, the rice industry would lose over $8.4 million net annually when the use of 2,4-D is compared with 2,4,5-T. Also, losses would increase with time because tolerant weed species would increase.

Propanil And 2,4-D

If propanil and 2,4-D were substituted for 2,4,5-T on all the rice now treated with 2,4,5-T, each herbicide would be used on about half of the acreage presently treated with 2,4,5-T (table 16). If they were used instead of 2,4,5-T rice farmers would spend only $221,000 more annually for herbicides. Because they are less effective than 2,4,5-T, rice production losses would be $5.2 million more each year than they are now with 2,4,5-T during the first 3-year cropping cycle (table 16). Therefore, when the cost of propanil and 2,4-D, and the production losses are compared with 2,4,5-T, the rice industry would lose more than $5.4 million annually. During the second 3-year cropping cycle, losses would be about $8.9 million compared with 2,4,5-T (table 21). Losses would increase with time because tolerant species such as northern jointvetch would build up.

Silvex, 2,4-D And Propanil

If silvex, 2,4-D, and propanil were substituted for 2,4,5-T on all the rice now treated with 2,4,5-T, silvex, 2,4-D, and propanil would be used on about 33, 20 and 47 percent of the rice, respectively (table 16). These three herbicides would be the best substitute treatment in the 2,4,5-T use areas. If they were used instead of 2,4,5-T rice farmers would spend about $337,000 more annually for herbicides. Because they are less effective than 2,4,5-T, rice production losses would be $3.8 million more each year than they are now with 2,4,5-T during the first 3-year cropping cycle (table 16). Therefore, when the cost of silvex, 2,4-D, and propanil, and the production losses are compared with 2,4,5-T, the rice industry would lose more than $4.2 million annually. During the second 3-year cropping cycle, losses would be about $6.7 million, compared with 2,4,5-T (table 21). Losses would increase with time because tolerant species such as northern jointvetch would increase.

Anticipated Availability of Other Herbicides

Adequate supplies of propanil and 2,4-D are available for weed control applications. Several chemical companies formulate each of these herbicides which makes for healthy competition and availability at a reasonable cost. Although one application of propanil at 3 lb/A costs about $3 per acre more than one application of 2,4,5-T, 2,4-D costs about $2 per acre less than 2,4,5-T (table 22). These costs almost balance and would not be a significant factor in affecting supply and demand. However, supplies of ester formulations of silvex are inadequate at the present time because less than 1 percent of the rice acreage is now treated with this herbicide (table 1). However, silvex inventories could be increased rapidly and supply would meet demand after a few years.

Environmental Effects

The use of chemical alternatives for 2,4,5-T may have an adverse environmental effect. Although propanil is low in phytotoxicity to nontarget crops, 2,4-D is very injurious to cotton and silvex damages soybeans severely (Smith et al. 1977). In the 2,4,5-T use areas cotton and soybeans are the major crops grown nearby ricefields (Smith et al. 1977). If the use of 2,4-D were increased in rice-producing areas where cotton is also grown, spray drift damage could increase to the point of adversely affecting cotton production. If the use of silvex were increased in rice-producing areas where soybeans are a major crop in the rotation, spray drift damage could increase to the level of reducing soybean yields and quality. Cotton and soybean farmers may retaliate and demand a ban on the use of 2,4-D or silvex for weed control in rice. In Arkansas over the past two decades, cotton farmers and other groups have tried on several occasions to obtain a ban on the use of 2,4-D for rice in cotton-growing areas; these movements have been associated with increased use of and injury from 2,4-D (Pay 1978a). Present State regulations prohibit the use of 2,4-D in rice-growing areas where cotton is intercropped with rice (Arkansas State Plant Board 1978). Every effort should be made to have available safe, effective herbicides for weed management in rice. Continuous minor losses to weeds, even when a full array of herbicides are available, suggest that any loss of weed control technology will result in increased weed infestations.

Cultural, Mechanical, and Hand Labor Alternatives

Management of cultural and mechanical weed control practices may be used effectively to control specific weeds (table 23, Smith et al. 1977).

Preventive methods of weed control are required to avoid weed problems before they begin in ricefields. Preventive methods include use of weed-free crop seed (table 23), use of irrigation water free of weed seed or other propagation parts, and use of clean equipment. Conformance to certified seed regulations and use of certified seed are related ways of avoiding weed seed contamination.

Practical cultural-mechanical weed control practices include summer fallowing, seedbed preparation, crop rotations, special seeding methods, management of irrigation water, and cultivation (Smith et al. 1977). Handweeding can also be used if weed infestations are sparse or isolated to small areas in the ricefield.

Table 23--Response of common ricefield weeds to selected cultural practices[a]

Weed	Hand Weeding[b]	Clean rice seed[b,c]	Seedbed preparation	Water seeding	Dry seeding	Timely flooding[d]	Timely draining[d]	Rice stand[e]	Summer fallow	Crop rotation
Alligatorweed	Poor	Poor	Good	Poor	Poor	Poor	Poor	Good	Good	Good
Arrowhead	Poor	Good	Good	Poor	Good	Poor	Fair	Good	Good	Good
Barnyardgrass	Poor	Good	Good	Good	Poor	Fair	Poor	Fair	Fair	Fair
Beakrush	Poor	Good	Good	Poor	Fair	Poor	Fair	Good	Good	Good
Broadleaf signalgrass	Poor	Good	Good	Good	Poor	Good	Poor	Fair	Fair	Fair
Bulrush	Poor	Poor	Good	Poor	Good	Poor	Good	Poor	Good	Good
Burhead	Poor	Poor	Good	Poor	Good	Poor	Good	Good	Good	Good
Cattail	Poor	Poor	Good	Poor	Good	Poor	Good	Poor	Good	Good
Cocklebur	Poor	Good	Good	Good	Poor	Good	Poor	Good	Poor	Poor
Common waterplantain	Poor	Poor	Good	Poor	Good	Poor	Good	Good	Good	Good
Dayflower	Poor	Good	Good	Poor	Poor	Fair	Poor	Good	Fair	Fair
Ducksalad	Poor	Poor	Poor	Poor	Fair	Poor	Good	Good	Poor	Poor
Eclipta	Poor	Poor	Poor	Good	Poor	Fair	Poor	Good	Fair	Fair
False pimpernel	Poor	Poor	Poor	Poor	Fair	Poor	Good	Good	Poor	Poor
Fimbristylis	Poor	Poor	Poor	Poor	Good	Poor	Good	Good	Poor	Poor
Gooseweed	Poor	Poor	Good	Poor	Good	Poor	Good	Good	Good	Fair

continued

Table 23--Response of common ricefield weeds to selected cultural practices[a] (continued)

Weed	Hand Weeding[b]	Clean rice seed[b,c]	Seedbed preparation	Water seeding	Dry seeding	Timely flooding[d]	Timely draining[d]	Rice stand[e]	Summer fallow	Crop rotation
Hemp sesbania	Good	Good	Good	Fair	Poor	Fair	Poor	Fair	Fair	Fair
Horned pondweed	Poor	Poor	Poor	Poor	Good	Poor	Fair	Good	Fair	Fair
Jointvetch	Good	Good	Good	Fair	Poor	Fair	Poor	Fair	Fair	Fair
Knotgrass	Poor	Poor	Good	Poor	Fair	Poor	Fair	Good	Good	Good
Mexicanweed	Good	Good	Good	Fair	Poor	Fair	Poor	Fair	Fair	Good
Morningglory	Poor	Good	Good	Good	Poor	Good	Poor	Good	Poor	Poor
Naiad	Poor	Poor	Fair	Poor	Good	Poor	Fair	Good	Fair	Fair
Panicum grasses:										
Annuals	Poor	Poor	Fair	Good	Poor	Fair	Poor	Good	Good	Good
Perennials	Poor	Poor	Good	Poor	Poor	Fair	Poor	Good	Good	Good
Pondweed	Poor	Poor	Good	Poor	Good	Poor	Fair	Good	Good	Good
Red Rice	Good	Good	Good	Fair	Poor	Poor	Poor	Fair	Good	Good
Redstem or purple ammannia	Poor	Poor	Poor	Poor	Fair	Poor	Good	Good	Poor	Poor
Smartweed	Poor	Good	Good	Poor	Fair	Poor	Poor	Good	Good	Good
Spikerush:										
Annuals	Poor	Poor	Fair	Poor	Fair	Poor	Good	Good	Good	Good
Perennials	Poor	Poor	Good	Good	Poor	Poor	Poor	Good	Good	Good
Sprangletop	Poor	Good	Fair	Poor	Poor	Poor	Poor	Good	Good	Good

continued

Table 23--Response of common ricefield weeds to selected cultural practices[a/] (continued)

Weed	Hand Weeding[b/]	Clean rice seed[b,c/]	Seedbed preparation	Water seeding	Dry seeding	Timely flooding[d/]	Timely draining[d/]	Rice stand[e/]	Summer fallow	Crop rotation
Umbrellaplant:										
Annuals	Poor	Poor	Fair	Poor	Fair	Poor	Good	Good	Good	Good
Perennials	Poor	Poor	Good	Fair	Poor	Fair	Poor	Good	Good	Good
Waterhyssop	Poor	Poor	Poor	Poor	Fair	Poor	Good	Good	Poor	Poor
Waterprimrose	Poor	Good	Good	Poor	Fair	Poor	Fair	Good	Good	Good

a/ From Smith et al, 1977. Ratings for classes of cultural practice: Good - practice can be used effectively in commercial rice to prevent or reduce weed infestations. Fair - practice can be used in commercial rice but usually gives only fair weed control. Poor - practice cannot be used economically in commercial rice or fails to control the weed.

b/ These practices are ineffectice if land is already contaminated with weed propagules.

c/ Seeding weed-free crop seed reduces problems with all weeds. A poor rating indicates that weed seeds do not usually contaminate seed rice. (Weed seeds are not harvested with the crop or can be removed easily with commercial cleaning equipment). A good rating indicates that the weed seeds are difficult to remove from the rice seed and special effort is required to remove the weed seeds.

d/ After crop emergence.

e A good rice stand of 12 to 20 plants per square foot helps reduce problems with many weeds.

SOURCE: USDA-SEA-AR, Stuttgart, AR.

Efficacy

Fallowing and Seedbed Preparation

Summer fallowing of riceland controls and reduces infestations of many broadleaf, aquatic, and sedge weeds that are controlled by 2,4,5-T (Smith et al. 1977). Weeds that this practice or 2,4,5-T reduce include: alligatorweed, arrowhead, beakrush, burhead, cattail, gooseweed, morningglory, pondweed, smartweed, spikerush, umbrellaplant, and waterprimrose (tables 4 and 23). Some broadleaf and aquatic weeds that are controlled by 2,4,5-T are not controlled well by fallowing; these include cocklebur, dayflower, ducksalad, eclipta, false pimpernel, fimbristylis, hemp sesbania, northern and Indian jointvetch, Mexicanweed, redstem, and waterhyssop. Because many of these weeds have hard seed that live in the soil for long periods (Smith et al. 1977), they are not reduced to practical levels by fallowing. Even if fallowing controlled weeds effectively, most farmers do not have capital or land reserves that would permit a large scale fallowing program. (Baldwin 1978). Consequently, 2,4,5-T or other herbicide applications are required to control these weeds in the rice crop.

Thorough seedbed preparation helps to control most weeds that infest ricefields. The goal is the elimination of all weed growth up to the time of planting. Repeated cultivations in the spring at 1- to 3-week intervals before seeding rice, reduce many weeds that are controlled by 2,4,5-T (Smith et al. 1977). These include alligatorweed, arrowhead, beakrush, cattail, gooseweed, hemp sesbania, northern and Indian jointvetch, Mexicanweed, morningglory, and others (tables 4 and 23). Although these weeds are reduced by preparing the seedbed well, many of them have seeds that contaminate the soil and remain viable for many years (Smith et al. 1977). The weed seed germinates after the rice crop is planted and must be controlled by other practices. Some troublesome weeds included in this category are hemp sesbania, northern jointvetch, and morningglory; these three can be controlled by 2,4,5-T.

Crop Rotation

Properly managed rotations combined with the use of herbicides are important for controlling many troublesome weeds of rice (table 23) (Smith et al. 1977). Keeping all crops in the rotation free of weeds reduces weeds in the rice crop. In the 2,4,5-T use areas of Arkansas, Mississippi, northern Louisiana, and Missouri, soybeans are frequently rotated with rice (Huey 1977). A common rotation is one year of rice and two years of soybeans. Rotating an upland row crop, e.g. soybeans, with rice is excellent for controlling perennial broadleaf weeds that are also controlled by 2,4,5-T; weeds controlled by this practice include alligatorweed, arrowhead, beakrush, burhead, cattail, smartweed, spikerush, umbrellaplant, and waterprimrose (table 23). However, many annual broadleaf and aquatic weeds that produce seed which remain viable for years in the soil, are not reduced by crop rotations. Seeds of these weeds germinate as soon as the land is returned to rice. 2,4,5-T is frequently required to control weeds of this category, e.g., hemp sesbania, northern jointvetch, morningglory, ducksalad, and redstem. Controlling weeds, e.g., hemp sesbania and northern jointvetch, in the rice crop helps lower infestations in rotation crops, e.g., soybeans; weed control technology in soybeans is inadequate to control these species (Baldwin 1978).

Seeding Method

Rice may be drill-seeded, broadcast-seeded in moist soil and disked or harrowed to cover, or water-seeded (Smith et al. 1977). The method of seeding influences subsequent weed growth and weed control. Water-seeding may be used selectively to control hemp sesbania, northern jointvetch, and morningglory (table 23). To be effective the water must be held at 4 inches for 3 to 4 weeks after seeding. Such management is frequently injurious to rice. It may be difficult to obtain an adequate rice stand, if the floodwater is kept on the field for long periods. Frequently the floodwater must be removed to favor rice growth. Consequently, during the drained period, weeds such as hemp sesbania, northern jointvetch, and morningglory germinate and grow. They must be controlled by 2,4,5-T or other herbicide applications. Even if the floodwater can be kept on the ricefield without damaging the rice, these weeds are not controlled on the levees. Therefore, levees must be treated with 2,4,5-T or other herbicide applications to control the above weeds. Water-seeding increases problems with aquatic species, e.g., ducksalad, redstem, gooseweed, waterhyssop, false pimpernel, and spikerush. When these weeds develop in water-seeded rice, they must be controlled with applications of 2,4,5-T or other herbicides.

Water Management

Timely flooding or draining reduce problems with many weeds that are also controlled by 2,4,5-T (tables 4 and 23, Smith et al. 1977). Applying floodwater to young morningglory weeds kills some species (table 18); however, plants growing on levees are not controlled by this practice. Also, willowleaf morningglory which grows in the paddy is not controlled by floodwater. These weeds must be controlled by 2,4,5-T or other herbicide applications.

Aquatic weeds that germinate and grow in flooded ricefields, can be reduced by timely draining (table 23) (Smith et al. 1977). Weeds that are reduced by this practice and by 2,4,5-T applications include the aquatic weed complex of ducksalad, false pimpernel, gooseweed, redstem, spikerush, umbrellaplant, and waterhyssop. Frequently, drying ricefields cannot be accomplished while the weeds are small and susceptible to desiccation because of rainy weather during the critical period. Also, drying sufficiently to kill the aquatic weed complex may desiccate and injure young rice. In addition, dried ricefields may become reinfested with grass weeds that must be controlled by applications of herbicides; drying ricefields also cause losses of nitrogen fertilizer. (Arkansas Cooperative Extension Service 1978e). Therefore, drying of ricefields to control weeds is not a dependable and predictable tool in a weed management system and can be costly. 2,4,5-T or other herbicide applications are frequently required to control weeds that cannot be controlled by drying methods.

Handweeding and Cultivation

Although handweeding is the main method of weed control in Asian countries (where rice is transplanted into rows), it is used only to remove scattered infestations in rice grown for seed in the U.S. (Smith et al. 1977, table 23). Mechanical cultivation methods, except for rotary hoeing, to remove weeds after the rice crop has been seeded are usually not practical. In drill-seeded (6-inch spacing) rice cultivation between rows to remove weeds is difficult because of levees, and in dry-broadcast or water-seeded rice cultivation is impossible.

Rotary hoeing soon after crop emergence controls small weeds in dry-seeded rice (Smith et al. 1977). It is the only practical method of cultivation after seeding, but it is seldom used because it is only effective on small weeds when the soil is neither too dry nor too wet. Also, levees interfere with this weed-control practice.

Consequently, 2,4,5-T or other herbicide applications are required to control weeds in ricefields that cannot be controlled by handweeding or cultivation.

Costs of Cultural Mechanical and Hand Labor Alternatives

Fallowing and Seedbed Preparation

Summer fallowing is an expensive and a relatively ineffective alternate to 2,4,5-T (Smith et al. 1977). If the land is fallowed, soybeans, grain sorghum, cotton, or lespedeza--important cash crops in the 2,4,5-T use area--are not produced. Per acre gross income in 1976 from these crops averaged $130 for soybeans, $110 for grain sorghum, $240 for cotton, and $130 for seed lespedeza (USDA-SRS 1977). Rice farmers cannot stand such massive losses of income on one-half to two-thirds of their tillable land.

Rice farmers are presently spending substantial amounts of money for seedbed preparation. In 1977 an estimated $40 per acre was spent on seedbed preparation; approximately one-half or $20 per acre of this cost is prorated to weed control (Mullins et al. 1978). Presently, farmers are doing an acceptable job in controlling weeds up to the time of seeding with seedbed preparation practices, especially the broadleaf-aquatic weed complex that is controlled by 2,4,5-T. Because weeds germinate after seeding the crop, additional inputs and costs for preplant seedbed preparation would not substitute for 2,4,5-T applications.

Seeding Method

Water-seeding rice for weed-control purposes is frequently not practical because farmers do not have sufficient water supplies to flood fields rapidly and the water frequently contains salts which prevent seeding rice into the water (Arkansas Cooperative Extension Service 1978e, Baldwin 1978). The practice of water-seeding to control weeds susceptible to 2,4,5-T requires an extra flooding and draining in the rice-production process (Huey 1976). This additional irrigation management costs about $7 per acre. Also, this practice requires about 40 pounds per acre of extra seed rice valued at $5 per acre (Huey 1977). Therefore, the direct effects of water-seeding for weed control cost rice farmers an extra $12 per acre. Because this practice intensifies problems with aquatic weeds, the farmer may have to make an extra application of propanil valued at $13 per acre to control aquatic weeds (table 22). The farmer may encounter yield and quality losses because propanil does not control aquatic weeds as effectively as 2,4,5-T; this loss is valued at $23 per acre (USDA-SEA-AR 1978). The direct cost of water-seeding and the indirect cost of applying extra herbicide and losses in yield and quality may cost the rice farmer as much as $48 per acre. Consequently, 2,4,5-T is needed for use in rice to prevent the need for water-seeding and the associated extra costs of production.

Water Management

Draining after permanent flooding to control the aquatic weed complex can be costly to the farmer. An extra draining and reflooding costs about $7 per acre (Huey 1976). Because nitrogen is usually applied by the time of permanent flooding, draining and reflooding decreases its efficiency as much as 50 percent (Huey 1976); if we assume a 20 percent loss, the additional nitrogen required costs about $2 per acre. During the drained-period, grass weeds may reinfest the ricefield and require an application of propanil valued at $13 per acre (table 22). Therefore, draining and flooding to control weeds that would normally be controlled by 2,4,5-T cost the rice farmer $22 per acre.

Flooding fields early to control such weeds as morningglory can be costly to the farmer. Frequently, early flooding injures rice growth with subsequent yield losses, especially on high pH soil (Huey 1977). Yield losses as high as 10 percent might be expected (Huey 1976); this loss is valued at $36 per acre. Therefore, 2,4,5-T is needed to control weeds and permit management of irrigation water in a way advantageous to the rice plant.

Handweeding and Cultivation

Handweeding for control of weeds reduced by 2,4,5-T is costly to rice farmers. Only a few weed species can be handweeded effectively (table 23, Smith et al. 1977). Handweeding sparse infestations of hemp sesbania and northern jointvetch requires 4 to 8 man hours per acre, valued at $12 to $24. Handweeding also causes some damage to the rice because walking through the field breaks down the rice plants (Arkansas Cooperative Extension Service 1978e).

Cultivation after seeding by rotary hoeing is so ineffective that this practice is not a viable alternate to 2,4,5-T (Smith et al. 1977).

Effect on Yield

Many of the cultural-mechanical-handweeding practices implemented specifically for weed control are injurious to rice (Smith et al. 1977, Huey 1977); such practices frequently reduce yield and quality of the crop. Fallowing land during the summer eliminates all crop production. The use of special seeding practices e.g., water-seeding may reduce rice stands and yields when practiced after temperatures become hot in late May and June. Early flooding or timely draining to control weeds may not favor rice growth; subsequently, yield and quality of the rice crop may be lowered. Walking through rice fields during mid-season to late-season growth stages to perform handweeding practices can break jointing rice plants with subsequent yield and quality reductions.

Anticipated Availability

The cultural-mechanical weed control practices are adequately available and are presently used extensively by rice farmers. However, they are only moderately effective for special weed-control problems and some are very costly to farmers (table 23, Smith et al. 1977). For example, fallowing, which does not permit crop production during one production cycle, is very costly to the farmer who usually cannot afford the loss of income from the land.

Hand labor to perform weed-control tasks in rice is generally not available to rice farmers. Presently only about 12 man hours, exclusive of labor for handweeding, are required to grow an acre of rice at a cost of $47 per acre; this includes labor for land preparation, irrigation, harvesting, and other practices (Mullins et al. 1978). Even if hand labor were available for weed-control tasks, the farmer could not afford to bear the cost. The use of hand labor to control weeds would double to quadruple the labor requirement for rice production; this would cost the farmer $100-$200 more per acre to produce rice and subsequently would limit or prohibit rice production because the cost of such practices would consume all of the profit.

If cultural-mechanical weed control inputs had to be increased because 2,4,5-T were unavailable, use of equipment and labor for machinery operations would increase. In 1977 rice farmers spent about $40 per acre for tractor and equipment fuel and repairs and for labor to operate the equipment (Mullins et al. 1978). The increased use of energy in times of short supply would be counter productive to the U.S. national policy of energy conservation. If weeds were not controlled with 2,4,5-T or other herbicides, it is estimated that farmers would have to spend 50 percent more than they do now for extra preplanting land preparation (Arkansas Cooperative Extension Service 1978e). Therefore, preplant operations (tractor and equipment fuel, repair, and labor) would cost the farmer a total of $60 per acre. Also, the farmer would need more laborers who are frequently unavailable to carry out these operations.

If hand labor were increased for weed control tasks because 2,4,5-T was unavailable, laborers would have to perform the difficult and mundane tasks of handweeding. Laborers for handweeding tasks are usually not available in sufficient quantities required for effective control of weeds that are controlled by 2,4,5-T (Arkansas Cooperative Extension Service 1978e). In addition, this would increase the cost of production and make rice growing unprofitable.

Because the use of cultural-mechanical-hand labor weed control practices instead of herbicides would lower rice yields and quality, rice supplies in the 2,4,5-T use areas of Arkansas, Mississippi, northern Louisiana, and Missouri would be reduced (Smith et al. 1977, Gerlow 1973). This would alter present processing and marketing channels with subsequent adverse effects on the rice industry (Gerlow 1973). Jobs and the economy in these rice-producing areas could be seriously altered.

Environmental Effects of Alternatives

The use of cultural, mechanical, and hand labor alternatives to 2,4,5-T would have only minor direct effects on the environment. Of the various management practices discussed, only summer fallowing and crop rotations would cause any direct effects on the environment.

As indicated above, summer fallowing is not a valid alternate to 2,4,5-T in a weed management program for rice (Arkansas Cooperative Extension Service, 1978e). Farmers cannot afford to let the land be idle during the summer. They must at least grow an alternate upland crop to produce needed income. Because fallowing land is an impractical alternate and would not be used by farmers as an alternate to 2,4,5-T, its effects on the environment will not be discussed.

Although cropping systems alone are ineffective in controlling most weeds controlled by 2,4,5-T (Smith et al. 1977), they could be used in combination with alternate herbicides, such as propanil, 2,4-D, and integration of both to reduce weeds if 2,4,5-T were unavailable. The practice of growing upland crops more frequently on land to reduce weeds controlled by 2,4,5-T may affect soil erosion and compaction, rice production, and sedimentation in the aquatic environment.

Terrestrial Environment

Cultural, mechanical, and hand labor alternatives to 2,4,5-T would have insignificant net effects on vegetation or animals inhabiting ricefields or crops rotated with rice except to increase the diversity of weed communities (USDA-SEA-AR 1978).

The more frequent use of upland crops such as soybeans, cotton, and grain sorghum could increase soil erosion (USDA-SEA-AR 1978). Land that grows upland crops in the 2,4,5-T use areas of Arkansas, Mississippi, Louisiana, and Missouri is not terraced or leveed. Consequently, water from heavy rains drains from upland fields faster than from leveed ricefields; the water running from the upland fields erodes the soil.

Also, frequent production of upland crops may contribute to soil compaction (USDA-SEA-AR 1978). Upland crops are usually grown in rows to permit cultivation. The use of heavy cultivation equipment several times during the growing season compacts the soil. Because rice is not cultivated, heavy cultivation equipment would not compact the soil after the crop is planted.

Cultural, mechanical, and hand labor practices would have insignificant effects on the environment as related to future management options and commodity production if managed so as to maintain a functional rice-cropping system. If a change in the cropping system was forced by elimination of needed herbicides, the environmental changes would be substantial.

Aquatic Environment

The use of cultural-mechanical weed control practices as alternatives to 2,4,5-T would have insignificant effects on water quality, animals, and downstream water users. However, the increased frequency of growing upland crops may increase sedimentation and turbidity in streams because of greater soil erosion (USDA-SEA-AR 1978). It is generally believed that cropping systems would not shift enough to alter the sedimentation problem. Presently less than 15 percent of the land in the 2,4,5-T use area is devoted to rice; upland crops are grown on the remainder (USDA-SRS 1977). Even if all the land were shifted from rice to upland crops, the change would have only minor impact on erosion and sedimentation.

Do Nothing

Effects on Yield and Quality

If no herbicide treatments were substituted for 2,4,5-T in the rice-growing areas of Arkansas, Mississippi, Louisiana, and Missouri, where this herbicide is being used, losses in yield and quality of the crop are estimated at 13 and 4 percent, respectively, during the first 3-year cropping cycle (table 19). On the 292,000 acres presently treated aerially with 2,4,5-T, the average yield and quality losses are estimated at about $43 and $13, respectively (USDA-SEA-AR 1978). If no controls are used, the total value of these losses are estimated at more than $14 million annually (table 16). During the second 3-year cropping cycle, yield and quality losses would average 16 and 5 percent, respectively (table 20).

Effects on Future Management Options and Commodity Production

If 2,4,5-T were canceled for use in rice in the Arkansas, Mississippi, northern Louisiana, and Missouri rice-producing areas, farmers would have ineffective weed control practices available for control of broadleaf, aquatic, and sedge weeds in rice (table 19). Although the use of cultural-mechanical-crop management weed-control practices would increase, they would be less effective than 2,4,5-T (tables 4 and 23). In addition, other herbicides, that are less effective on ricefield weeds, would have to be substituted for 2,4,5-T to reduce losses and permit rice farmers to continue in business (table 4). Many of these alternate herbicides are more costly than 2,4,5-T (table 22); thus, the farmer would spend more for weed control inputs than he does now, a move which would reduce profits directly. In the short term some of the newer herbicides are available only in limited quantities, and could not be supplied to farmers in sufficient amounts to carry out weed-control programs.

In summary, yield and quality losses and increased costs for weed control inputs would have adverse effects on the rice farmer, the rice industry, and agribusiness in rice-producing areas of Arkansas, Mississippi, northern Louisiana, and Missouri.

If 2,4,5-T were not used on the 292,000 acres presently treated aerially, the average per acre yield would be reduced from 44 to 38 cwt. (tables 3 and 19). In addition, the rough rice would be contaminated with large quantities of weed seed which would lower the grade of the rice (table 11). Rice farmers are receiving about $160 per acre net returns above variable and fixed costs (Arkansas Cooperative Extension Service 1978c). No control of broadleaf, aquatic, and sedge weeds would result in the loss of $56 per acre (USDA-SEA-AR 1978). Therefore, if weeds susceptible to 2,4,5-T were not controlled, net returns above variable and fixed cost would be only about $100 per acre. After 4 to 6 years, yield and quality losses would be even greater because resistant weeds would build up (tables 19 and 20).

The loss of $56 per acre might appear to be a relatively small percentage of the total income from the crop. This loss, however, is all absorbed by the farmer since the overhead for the production system is constant. In rice, as for other cropping systems, the farmers' income is the residue after milling, shipping, and sales costs have been deducted from retail income. Small changes in retail prices, therefore, have a disproportionately heavy impact on farm price and future cropping systems. Consequently, there is a high uncertainty factor in the farmers' income.

Significant change in profits from rice production would shift rice land to production of more profitable crops, e.g. soybeans, grain sorghum, and cotton. The reduced rice production in the Mississippi Valley areas would adversely affect rice supplies and the existing processing and marketing patterns (Gerlow 1973). Other rice-producing states would supply the market for high-quality rice now produced in the 2,4,5-T use areas. Such drastic changes in rice production would affect the entire agribusiness of rice-producing areas of Arkansas, Mississippi, northern Louisiana, and Missouri.

Marketing patterns in the 2,4,5-T use areas of Arkansas, Mississippi, northern Louisiana, and Missouri indicate that most of the production is high-quality rice that moves into domestic and foreign dollar markets (table 7, Gerlow 1973). If these areas are unable to meet demands for high-quality rice, other rice-producing states, e.g., Texas, would shift some of their high-quality export rice into these markets. Such shifts would alter existing marketing agencies now active in the 2,4,5-T use areas. Dollar rice markets could also be affected since the major asset of the U.S. rice industry is high-quality rice (Gerlow 1973). Exports of inferior-quality rice could mean losses in dollar sales and in foreign exchange for the U.S. The rice carryover could increase and the U.S. Government would have more rice to move through Federal programs that use lower quality rice.

ECONOMIC IMPACT FROM LOSS OF 2,4,5-T

To summarize the expected revenue losses from the lack of 2,4,5-T during the first two cropping cycle periods, it is necessary to express each year's loss in terms of value as of a base year. This is accomplished by discounting the estimated future revenue losses and reduced spray costs without 2,4,5-T back to a present value for 1978, using a rate of 7 percent. This is a reasonable procedure because a $1 loss in 1979 or any future year, is worth less to a rice producer than a $1 loss in 1978.

Reductions in the total value of rice (given current prices) from lower production and increased downgrading due to weed competition and weed associated foreign matter in the harvested rice are expected to be $3.6, $3.3, $3.1, $4.9, $4.5, and $4.2 million at the end of the first, second, third, fourth, fifth, and sixth year respectively, without 2,4,5-T if silvex, 2,4-D, and propanil are available (table 24) ceteris paribus. If silvex, which is similar to 2,4,5-T becomes unavailable, reductions in total value of rice would be expected to increase to $4.8, $4.5, $4.2, $6.6, $6.2, and $5.8 million respectively, during the first six years that both 2,4,5-T and silvex are unavailable ceteris paribus. Added to these losses would be the increased cost of the alternative, less-effective, weed-control programs (table 16). When the higher costs of alternative control programs are considered, the total impacts on net present income to rice producers from the use of the alternative weed control programs are, ceteris paribus $3.9, $3.6, $3.4, $5.1, $4.8, and $4.5 million respectively during the first six years if silvex, 2,4-D, and propanil are available (table 24). Again, if silvex becomes unavailable, the total impact would be $5.0, $4.7, $4.4, $6.8, $6.3, and $5.9 million respectively, during the first six years. It is stressed

Table 24--Summary of short and mid-term losses in rice if 2,4,5-T is unavailable for weed control[a]

Alternative and year	Reduced grower revenue discounted to 1978	Increased weed-control costs without 2,4,5-T discounted to 1978	Total impact discounted to 1978
	Thousands of dollars		
Silvex, 2,4-D, & Propanil:			
End of year 1..........	3,573[b]	315[b]	3,888
2..........	3,339	294	3,633
3..........	3,121	275	3,396
4..........	4,850[c]	257[c]	5,107
5..........	4,532	240	4,772
6..........	4,236	225	4,461
	23,651	1,606	25,257
2,4-D & Propanil:			
End of year 1..........	4,797[d]	207[d]	5,004
2..........	4,483	193	4,676
3..........	4,190	180	4,370
4..........	6,596[c]	169[c]	6,765
5..........	6,165	158	6,323
6..........	5,761	147	5,908
	31,992	1,054	33,046

a/ Two best alternative weed-control programs from tables 16 and 21 are shown for comparison purposes.

b/ Years 1 to 3 discounted from 4 state summary in table 16, i.e. reduced revenue, column 9=$103,925,000-100,102,000 $3,823,000 x 7% discount factor = $3,573; increase cost, column 5=$3,112-2,775=$337 x 7% discount factor = $315.

c/ Years 4 to 6 discounted from 4-state summary in table 21 similar to above.

d/ Years 1 to 3 discounted from 4-state summary in table 16 similar to above.

SOURCE: Natural Resource Economics Division, Economics, Statistics, and Cooperatives Service, U.S. Department of Agriculture, Corvallis, OR.

that these impact estimates assume ceteris paribus conditions in rice production and marketing.

Average gross return for rice in the four states using 2,4,5-T to control weeds in rice is estimated to be $347 per acre (table 25). This estimate is the weighted average value received by farmers during the 1975, 1976, and 1977 seasons. Average production costs in the four states with 2,4,5-T are $255 per acre. Thus, the average returns to land, overhead, risk, and management for rice in the four states is $92 per acre with 2,4,5-T. Average returns to land, overhead, risk, and management with 2,4,5-T are expected to decrease from $92 per acre per year to $78 per acre per year during the first rotation period (table 25). During the second rotation period (second three years), average returns are expected to decrease to $72 per acre per year.

Additional losses are expected if 2,4,5-T and silvex are both unavailable. Average returns to land, overhead, risk, and management without 2,4,5-T and silvex are expected to decrease from $92 per acre per year to $74 per acre per year during the first rotation period (table 26). During the second rotation period (second three years), average returns are expected to decrease to $62 per acre per year.

Expected changes in rice production in the four states due to a lack of 2,4,5-T for weed-control in rice are small compared to U.S. total rice production and range from .04 to .08 percent of U.S. rice production (table 27). However, in the 2,4,5-T use area these yield losses represent 0.7 to 1.6 percent of the total production (table 27).

If 2,4,5-T and other herbicides are unavailable for use in rice, farmers may substitute soybeans or other crops for rice because alternate crops may be more profitable than rice. Comparing the per-acre returns for rice without 2,4,5-T and silvex (tables 25 and 26) to the per-acre returns for soybeans (tables 28 and 29) suggests that rice farmers in Louisiana, Mississippi, and Missouri might shift rice to soybeans if 2,4,5-T and silvex become unavailable. Annual per-acre returns for rice and soybeans compare as follows:

Table 25--Average annual per-acre returns to land, overhead, risk, and management with and without 2,4,5-T on the 292,000 acres of rice needing a herbicide treatment, such as 2,4,5-T, in Arkansas, Mississippi, Louisiana, and Missouri, treated year, and first and second rotation in untreated period a/

No. years without 2,4,5-T	Gross returns with 2,4,5-T b/	Increased costs & loss of gross returns per acre c/	Gross returns without 2,4,5-T	1975-77 Production costs d/	Returns to land, overhead, risk, and management
	Dollars				
Arkansas:					
0..................	377	0	377	255	122
1-3................	377	12	365	255	110
4-6................	377	20	357	255	102
Mississippi:					
0..................	327	0	327	254	73
1-3................	327	18	309	254	55
4-6................	327	27	300	254	46
Louisiana:					
0..................	305	0	305	254	51
1-3................	305	17	288	254	34
4-6................	305	25	280	254	26
Missouri:					
0..................	347	0	347	248	99
1-3................	347	21	326	248	78
4-6................	347	31	316	248	68
Average, 4 states:					
0..................	347	0	347	255	92
1-3................	347	14	333	255	78
4-6................	347	23	327	255	72

continued

Table 25--Average annual per-acre returns to land, overhead, risk, and management with and without 2,4,5-T on the 292,000 acres of rice needing a herbicide treatment, such as 2,4,5-T, in Arkansas, Mississippi, Louisiana, and Missouri, treated year, and first and second rotation in untreated period a/ (Continued)

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a/ Returns to land, overhead, risk, and management were estimated assuming *ceteris paribus* conditions with respect to price and production levels.

b/ Average per acre gross returns for 1975-1977 (table 5).

c/ Calculated from tables 16 and 21. Loss with best alternate ÷ acres treated = increased costs and loss of gross return per acre, i.e. example for Arkansas from table 16 is: \$2,007,000 ÷ 172,000 = \$11.67 and from table 21 is \$3,502,000 ÷ 172,000 = \$20.36.

d/ Mullins, et al 1978.

SOURCE: Natural Resource Economics Division, Economics, Statistics, and Cooperatives Ser., U.S. Dept. of Agric., Corvallis, OR.

Table 26--Average annual per-acre returns to land, overhead, risk, and management with and without 2,4,5-T and silvex on the 292,000 acres of rice needing a herbicide treatment such as 2,4,5-T, in Arkansas, Mississippi, Louisiana, and Missouri, treated year, and first and second rotation in untreated period a/

No. years without 2,4,5-T	Gross returns with 2,4,5-T b/	Increased costs & loss of gross returns per acre	Gross returns without 2,4,5-T	1975-1977 Production costs c/	Returns to land, overhead, risk, and management
	----------	----------	----dollars----	----------	----------
Arkansas:					
0................	377	0	377	255	122
1-3..............	377	16	361	255	106
4-6..............	377	28	349	255	94
Mississippi:					
0................	327	0	327	254	73
1-3..............	327	22	305	254	51
4-6..............	327	34	293	254	39
Louisiana:					
0................	305	0	305	254	51
1-3..............	305	21	284	254	30
4-6..............	305	32	273	254	19
Missouri:					
0................	347	0	347	248	99
1-3..............	347	23	234	248	76
4-6..............	347	35	312	248	64
Average, 4 States:					
0................	347	0	347	255	92
1-3..............	347	18	829	255	74
4-6..............	347	30	317	255	62

continued

Table 26--Average annual per-acre returns to land, overhead, risk, and management with and without 2,4,5-T and silvex on the 292,000 acres of rice needing a herbicide treatment such as 2,4,5-T, in Arkansas, Mississippi, Louisiana, and Missouri, treated year, and first and second rotation in untreated period a/ (Continued)

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a/ Returns to land, overhead, risk, and management were estimated assuming ceteris paribus conditions with respect to price and production levels.

b/ Average gross returns for 1974-1976.

c/ Mullins, et al 1978.

SOURCE: Natural Resource Economics Division, Economics, Statistics, and Cooperatives Service, U.S. Dept. of Agri., Corvallis, OR.

Table 27--Estimated annual rice production loss from the lack of 2,4,5-T and silvex, total for four states in Lower Mississippi region and percent of U.S. rice production a/

Alternatives and number of years without 2,4,5-T	Production loss each year	Percent of U.S. Rice production	Percent of 2,4,5-T use area b/
	Thousands CWT	Percent	Percent
Silvex, 2,4-D and propanil			
1 - 3	340.7	.036	0.720
4 - 6	561.7	.060	1,186
2,4-D and propanil			
1 - 3	443.3	.047	.936
4 - 6	753.2	.080	1.591

a/ Two best alternative weed-control programs are shown for comparison purposes.

b/ In the 2,4,5-T use area, an average 47,338 thousand cwt of rice was produced in 1975-77.

SOURCE: Natural Resource Economics Division, Economics, Statistics, and Cooperatives Service, U.S. Dept. of Agri., Corvallis, OR.

Table 28--Average annual per acre returns to land, overhead, risk, and management for soybeans in the rice-producing areas of Arkansas, Louisiana, Mississippi, and Missouri

Area	1975-77 gross returns a/	1975-77 Production costs b/	Returns to land, overhead, risk, and management
	Dollars		
Arkansas.............	125	72	53
Louisiana............	133	71	62
Mississippi..........	129	74	55
Missouri.............	144	74	70

a/ See table 29.

b/ Draft budgets obtained from Arkansas Cooperative Extension Service (1978d).

SOURCE: Natural Resource Economics Division, Economics, Statistics, and Cooperatives Service, U.S. Department of Agriculture, Corvallis, OR.

Table 29--Acres, production, and value of soybeans, United States, Arkansas, Louisiana, Mississippi, and Missouri, 1975-1977 a/

Area and year	Acres: Planted	Acres: Harvested	Yield per acre	Production	Value per bushel	Value per acre	Value of production
	----1,000 acres----			1,000 Bu	-------Dollars--------		1,000 dollars
United States:							
1975.........	54,732	53,761	28.8	1,546,120	4.60	132	7,000,340
1976.........	50,327	49,443	25.6	1,264,890	7.32	187	9,254,208
1977.........		57,911	29.6	1,716,334	5.79	172	9,937,574
Average.....		53,705	28.1	1,509,115	5.79	163	8,730,707
Arkansas:							
1975.........	4,750	4,700	24.5	115,150	4.50	110	507,600
1976.........	4,360	4,320	18.0	77,760	7.15	122	555,984
1977.........		4,600	22.0	101,200	6.30	139	637,560
Average.....		4,540	21.6	98,037	5.78	125	567,048
Louisiana:							
1975.........	2,000	1,920	24.5	47,040	4.70	115	205,296
1976.........	2,150	2,120	26.0	55,120	6.85	178	377,572
1977.........		2,680	23.5	62,980	5.80	115	307,284
Average.....		2,240	24.6	55,047	5.39	133	296,817
Mississippi:							
1975.........	3,230	3,120	22.5	70,200	4.65	105	319,176
1976.........	3,335	3,250	22.0	71,500	6.90	152	493,350
1977.........		3,650	20.5	74,825	6.35		475,139
Average.....		3,340	21.6	72,175	5.95	129	429,222

continued

Table 29—Acres, production, and value of soybeans, United States, Arkansas, Louisiana, Mississippi, and Missouri, 1975-1977 a/ (continued)

Area and year	Acres: Planted	Acres: Harvested	Yield per acre	Production	Value per bushel	Value per acre	Value of production
	----1,000 acres----			1,000 Bu	-------Dollars--------		1,000 dollars
Missouri:							
1975.........	4,550	4,470	26.0	116,220	4.55	118	518,632
1976.........	4,300	4,200	20.0	84,000	7.25	145	609,000
1977.........		4,800	30.0	144,000	5.65	107	813,600
Average.....		4,490	25.6	144,740	5.64	144	647,077

a/ Data for 1975 and 1976 taken from 1977 Agricultural Statistics. Harvested acres, yield, and production data for 1977 taken from USDA, ESCS, SRS, "Crop Production" report, released August 10, 1978. Price data for 1977 taken from USDA, ESCS, Crop Reporting Board, "Agricultural Prices - Annual Summary, 1977", June, 1978.

SOURCE: Natural Resource Economics Division, Economics, Statistics, and Cooperatives Service, U.S. Department of Agriculture, Corvallis, OR.

	Rice				
	Without 2,4,5-T		Without 2,4,5-T & silvex		
	1-3 years	4-6 years	1-3 years	4-6 years	Soybeans
	Dollars				
Arkansas	110	102	106	94	53
Louisiana	34	26	30	19	62
Mississippi	55	46	51	39	55
Missouri	78	68	76	64	70

Assuming ceteris peribus conditions with respect to price and production levels, soybeans, may be substitued for rice in Louisiana, Mississippi, and Missouri if 2,4,5-T and silvex become unavailable.

CHAPTER 5

THE BEHAVIOR AND IMPACT OF 2,4,5-T AND TCDD IN THE ENVIRONMENT

SUMMARY

Spray drift of herbicides is an acknowledged concern. Effects on plants off the target area has led to detailed research studies to define the variables and develop solutions. Several states have enacted regulations which are designed to reduce unintended effects due to drift while still permitting the use of herbicides. Equipment and methodology are available to reduce drift to a low level. Avoiding drift entirely, especially from aerial applications, is not currently possible. Proper attention to formulation and to atmospheric and application factors will maximize on target deposition and minimize off-site damage.

In soils, 2,4,5-T does not persist in significant amounts from one year to the next. Soil microorganisms play a leading role in their detoxification. Plants (weeds and crops) are main receptors of foliar-applied 2,4,5-T. Herbicide residues in or on vegetation may be as high as 300 ppm, but residues decline rapidly thereafter by plant metabolism, photodegradation, volatilization, and removal by rainfall. Deferred grazing on pastures and rangeland to allow for release of forage species also allows time for residues to disappear. Movement of 2,4,5-T can occur in surface runoff water if heavy rainfall occurs soon after treatment. However, loss of herbicide from treated areas by movement in runoff water is usually a very small percentage of the total herbicide applied. 2,4,5-T rapidly dissipates in streams by dilution and is difficult to detect some distance downstream from the point of application. In impounded water, 2,4,5-T disappears rapidly, especially if adapted microorganisms are present. The possibility of these herbicides contaminating groundwater supplies is very unlikely. Residues of 2,4,5-T rarely occur in meat, milk, and other agricultural products when label directions are followed in current patterns of use. 2,4,5-T does not accumulate in animal tissues and is rapidly excreted in man and animals should intake occur.

There is substantially less literature on TCDD than on 2,4,5-T, but there are sufficient data to make reasonable inference to the behavior of TCDD in the environment. TCDD has a short half-life (1 day) when it is on vegetation in the presence of a hydrogen donor. Photochemical degradation also occurs on soil (half-life about 50 hours). In the absence of light, TCDD has a half-life in soil of one year. TCDD is not mobile in soil, thus groundwater contamination is highly unlikely to occur from currently registered uses of 2,4,5-T. TCDD residues have not been measured in vegetation soil or water after the application of 2,4,5-T. Assuming specific levels of TCDD in 2,4,5-T and applying coefficients derived from controlled experiments for degradation, it is possible to calculate the level of TCDD which may be present in specific parts of the environment after application of 2,4,5-T. TCDD will bioaccumulate in organisms which have a substantive and continuing exposure to this chemical. In the natural environment, several processes operate to reduce or eliminate organism exposure. Environmental monitoring indicates substantial bioaccumulation of TCDD (sufficient to produce residues in excess of 10 ppt in the majority of the population) is not occurring in animals in or near areas treated with 2,4,5-T in current operational programs. TCDD can be produced by combustion of 2,4,5-T treated material (under special conditions) but because of the rapid decomposition of 2,4,5-T, burning of treated vegetation is not expected to produce levels of TCDD greater than those present immediately after the application of the herbicide.

Humans not involved in the application of 2,4,5-T could conceivably be exposed to 2,4,5-T or TCDD in air, food, or water. TCDD levels have usually not been measured but can be estimated from the level of 2,4,5-T. In areas of heavy use, 2,4,5-T concentrations in the air may average 0.1 mg/m^3 within a few hundred feet of sprayed areas. National surveys for 2,4,5-T in food and water fail to detect the herbicide in all but a small percentage of the samples.

Applicators will receive the most substantial exposure to 2,4,5-T because they are most likely to come in contact with the herbicide in its concentrated form on a regular basis. Analysis of the actual patterns of use of 2,4,5-T in the four commodity groups covered by this report shows worker exposure to spray material varies from 1 minute to 165 hours per year. The number of individuals involved in some phase of application is estimated to be about 15,424 with a weighted average exposure of 24 hours per year.

The selection of assumptions for exposure scenarios has a substantial impact on calculated margins of safety. The use of assumptions which more accurately reflect actual exposure situations than those used in the PD-1 generated a series of correction factors which were used to calculate adjusted exposure levels for four scenarios used in PD-1. These adjusted exposure levels were used with the no-adverse-effect levels cited by EPA in PD-1 to calculate adjusted margins of safety. The PD-1 and the adjusted margins of safety are compared below:

Exposure scenario	Margin of safety			
	2,4,5-T		TCDD	
	PD-1[a/]	AT[b/]	PD-1	AT
2. Dermal exposure - backpack sprayer	3	5.6×10^3	43	4.1×10^4
3. Dermal exposure - tractor mounted boom	11	1.1×10^6	167	8.8×10^6
4. Dermal exposure - aerial application	312	3.9×10^7	6.0×10^3	3.0×10^8
5. Inhalation - aerial application	870	7.2×10^5	1.5×10^4	1.2×10^7

a/ Margin of safety calculated from PD-1.

b/ Adjusted margin of safety corrected by the Assessment Team using the factorial method.

Using data from 2 experiments involving dermal absorbtion of 2,4,5-T by humans, applicator exposure was also calculated on an absolute basis for several exposure situations. Human absorbtion of 2,4,5-T is estimated to range from less than 0.001 mg/kg/hr to a maximum of 0.076 mg/kg/hr when exposed skin is wet with spray for the entire application period. The addition of long-sleeved shirt and gloves would reduce exposure 91 percent. In a test of operational application by helicopter, tractor, and backpack sprayers, short-sleeved applicators were exposed to an average of 0.0003, 0.0012, and 0.0123 mg/kg/hr. Both the factorial and the absolute basis show that applicator exposure is substantially less than estimated in PD-1.

The herbicide 2,4,5-T is practically nontoxic to soil organisms and the soil microbial population is partially responsible for its breakdown. In acute or subacute exposure tests, 2,4,5-T is moderately toxic to some species of fish and only slightly toxic to lower aquatic organisms, birds, and wild animals under laboratory conditions. Herbicides containing 2,4,5-T are moderately toxic to laboratory mammals by acute or subacute oral and dermal intake and are only slightly toxic by inhalation. In the field, 2,4,5-T is not usually present at acute or subacute levels when used according to current label instructions.

2,4,5-T appears to cause the greatest effect on the environment through alteration of the density and species composition of the vegetative community. This alteration is usually the intended purpose of weed and brush-control projects and will occur regardless of the alternative technique used.

INTRODUCTION

The main environmental effect of 2,4,5-T is to produce changes in the density and species composition of vegetation by controlling broadleaf plants. These changes produce indirect environmental effects which were discussed as part of chapters 1, 2, 3, and 4 for specific commodities. This chapter deals with the movement, persistence, and fate of 2,4,5-T and TCDD in the environment and the exposure that this behavior produces for nontarget species. Special attention is given to analysis of the exposure applicators may receive from the current patterns of 2,4,5-T use.

The chapter has 7 major sections. The first section deals with spray drift both in a theoretical and a practical sense. A second section deals with the initial amounts deposited and the subsequent fate of 2,4,5-T in soil, vegetation, water, animals, and off-target sites. Data from research, residue monitoring and large scale surveys of 2,4,5-T in the environment are included. Processes of breakdown and disappearance of 2,4,5-T are also included for each environmental component. A third section reviews the state of knowledge of the environmental behavior of TCDD. Other sections give (1) data on the probable routes and amount of exposure of applicators and the general population to 2,4,5-T via air, food and water sources, (2) the consequences of exposure, and (3) the ecological effects of 2,4,5-T use.

PART 1: SPRAY DRIFT, SOME THEORETICAL AND PRACTICAL CONSIDERATIONS

Drift is defined as the airborne transport of spray droplets away from the point of release. Movement of herbicides may also occur by vaporization and subsequent air movement. Because the formulations of 2,4,5-T in common use today are usually nonvolatile amines or low-volatile esters, 2,4,5-T is not likely to occur at significant levels in the atmosphere following an application. Although research on spray drift has not received the attention it merits, a selected bibliography published in 1974 (Anonymous 1974) lists 195 pages of references.

An important point for the reader to bear in mind is that even small amounts of drift of 2,4,5-T can cause visible symptoms on off-site plants. Although chemicals that are not phytotoxic may contaminate an area without anyone suspecting their presence, the presence of phenoxy herbicides is always conspicuous. The response of sensitive species such as cotton, tomato, potato, peas, beans, and a number of common weeds indicate the presence of even small amounts of this herbicide.

THEORETICAL ASPECTS OF SPRAY DRIFT

The theory of spray drift is based on Stokes Law which describes the motion of a sphere through a fluid-like medium such as air. A modification of Stokes' equation (Hansen 1965) commonly used in drift studies is:

$$D = 1.49 \left(\frac{10^4 VH}{r^2}\right) \qquad (1)$$

where:
D = drift in feet
H = height above ground in feet
V = crosswind velocity in mph
r = droplet diameter in um

Using the modified equation, the drift of spray droplets in a 5 mph crosswind from a height of 100 feet would be as shown in table 1. The

Table 1--Theoretical drift of spray droplets released 100 feet above ground in a five mile per hour crosswind.

Droplet size, diameter	Theoretical drift,
µm	feet
50	298
100	74
200	19
400	4.6
600	2.0
800	1.2
1000	0.7
1500	0.3

drift distances resulting from other crosswind velocities or other release heights can be determined by applying an appropriate factor to the distances given or by calculation using the modified Stokes equation. Thus droplet size is the critical factor determining spray drift, since halving the droplet diameter results in a fourfold increase of drift distance.

A spray droplet is also subject to evaporation while falling. A very small droplet can evaporate completely before reaching the ground or a leaf surface. Assuming an air temperature of 86°F, relative humidity of 50 percent, and still air, the approximate lifetime and distance of fall for water droplets would be as shown in table 2 (Akesson and Yates 1978). The tabulation shows that water droplets less than 100 um diameter would probably never reach the ground or a leaf surface when applied from a height of 10 feet, an approximate minimum for aerial application.

The lifetimes and fall distances for herbicide spray droplets would vary from the figures given above. The kind of carrier (oil or water), vapor pressure of the carrier and the herbicide, and the kind of emulsion (oil in water or water in oil) would all influence droplet lifetime. Air turbulence causes major deviations from calculated fall-out rates.

The amine formulations of 2,4,5-T are essentially nonvolatile, even at high summer temperatures. Esters have a range of volatility that is correlated with the length and structure of the alcohol portion of the ester molecule. Ester formulations having an alcohol chain of five carbons or less are commonly classed as high-volatile esters. Low-volatile esters have longer alcohol moieties. The vapor pressures of various esters of 2,4-D in mm of Hg at a temperature of 187°C have been determined in order of decreasing vapor pressure to be: isopropyl, 17; butyl, 9.2; pentyl, 7.7; propylene glycol butyl ether, 3.9; butoxy ethanol, 3.9; 2-ethyl hexyl, 3.0; and isooctyl, 2.7. While the vapor pressures for equivalent esters of 2,4,5-T are not all known, it appears they are lower than for 2,4-D. The following values were reported for

Table 2--Lifetime and fall distance of water droplets in air[a,b]

Droplet size, diameter	Lifetime	Fall distance
μm	seconds	inches
200	56	1678
100	14	151
80	9.5	36
50	3.5	11
40	2.4	2
20	0.6	less than 1
10	0.2	less than 1
2	0.1	less than 1

a/ Akesson and Yates (1978)

b/ 86°F, 50% relative humidity, still air esters of 2,4,5-T: butyl, 4.5; pentyl, 3.9; 2-ethyl hexyl, 1.8 (Flint et al. 1968, Grover 1976). Low-volatile esters are more commonly used. The use of high-volatile esters is specifically prohibited in some states.

PRACTICAL ASPECTS OF SPRAY DRIFT

Drift during application is to some extent swath displacement, which is essentially a matter of moving the spray swath downwind. However, since fine particles move further downwind than larger ones, the swath is not only displaced, but is dispersed to some extent. It is easy to compensate for swath displacement by altering the path of the spray equipment. Reducing swath dispersion is more difficult.

Most of the application equipment in use today produce a range of droplet sizes. The greater the volume of spray solution found in small droplets (less than 100 um), the greater the drift. However, there is an upper range of droplet sizes beyond which biological effect of a herbicide is reduced. Thus, herbicide applications should have the goal of achieving a range of droplet sizes that minimizes drift without unduly sacrificing biological effectiveness. The factors that influence droplet size and drift will be discussed separately to permit an easier understanding of the principles involved.

MECHANICAL FACTORS

There are only five factors in conventional spray application equipment that can be varied to affect droplet size (Stewart and Gratkowski 1976). (1) Increasing air speed results in smaller droplets because of the greater shear forces imposed on the spray solution as it leaves the nozzle. (2) Pressure in the spray system also affects droplet size. Higher pressure increased turbulence in the nozzle, which in turn increases shear forces at the nozzle orifice, resulting in smaller droplets being formed. (3) Orifice diameter of nozzles is directly related to droplet size. A larger orifice will reduce shear forces caused by turbulence in the nozzle, and larger droplets will be produced. (4) The kind of nozzle also affects droplet size. Six types of hydraulic pressure nozzles are used for aerial spraying: hollow cone with whirl plate, hollow cone with offset entrance, fan, full cone, cylindrical jet, and flooding nozzles (Stewart and Gratkowski 1976). Nozzles producing narrow, cylindrical patterns form fewer small drops, thus they are better for reducing drift. Maximum reduction is possible by using cylindrical jet nozzles or hollow cone nozzles without the whirl plate that discharge the spray as a narrow, solid stream. (5) Nozzle orientation is a major factor affecting droplet size. The smallest range of droplet sizes and the lowest volume of spray solution in small droplets is obtained when nozzles are oriented parallel to the airstream and discharge downwind to the direction of air flow. As the angle of release relative to the airstream increases, shear forces increase and a greater number of small droplets are formed.

Equipment is available that will provide droplet sizes of 300-400 vmd (volume median diameter in um) with 70 to 90 percent recovery in a 500 foot width; 400-600 vmd with 85 to 95 percent recovery; 800-1000 vmd with 95 to 98 percent recovery; and 800 to 1000 vmd with 99 or more percent recovery (Akesson and Yates 1978).

ATMOSPHERIC FACTORS

Temperature and relative humidity influence drift through evaporation, which reduces droplet size and results in more drift. In practice, many states impose limitations to herbicide application based on these two factors. Limitations are also imposed in terms of maximum permissible windspeed at the time of application. A maximum windspeed of 5 mph is common, although up to 10 mph is permitted in areas where there is less hazard to sensitive vegetation.

A critical atmospheric factor is the temperature gradient with height, specifically the occurrence of warm air overhead, usually referred to as an inversion condition (Akesson and Yates 1978). An inversion limits vertical air circulation and acts to concentrate fumes and small particles in a cloud under the inversion ceiling, relatively close to the ground. The material thus entrapped may be transported long distances in amounts sufficient to cause damage to sensitive crops.

SPRAY SOLUTION FACTORS

Spray solutions can be modified to reduce the number of small droplets and thereby reduce drift. The principles involved are the increase of viscosity or surface tension, each of which tends to reduce the number of small droplets. The types of preparations available to reduce drift may be classified as invert emulsions, thickeners, particulating agents, and foaming agents (Gratkowski and Stewart 1973).

Invert emulsions are formulations in which water droplets are dispersed within a continuous oil phase. Mayonnaise is an invert emulsion with physical characteristics resembling invert spray mixtures. Viscosity of such emulsions depends on the ratio of oil to water. Because viscosity can be increased, the spray drops can be increased to very large sizes if desired. Another advantage is that the oil that surrounds each water droplet vaporizes more slowly than water and less droplet volume is lost during fall. However, some small droplets are still produced so drift is not eliminated. Thick invert emulsions are applied with special equipment designed to throw the material in large chunks.

Thickening agents are water-soluble polymers that increase the viscosity of spray solutions. They increase droplet size, but do not eliminate all small droplets. A more recently developed thickening agent is a polyvinyl polymer. In addition to increasing droplet size, it also seems to reduce the formation of small droplets.

Particulating agents are granular polymers. Each granule swells to a limited size, and is essentially a separate entity when sprayed. Droplet sizes can be more accurately controlled by this means than with thickeners. Specialized equipment is needed for effective application of solutions to which particulating agents have been added. Despite some advantages, use of particulating agents has never become widespread, and it does not appear that use will increase.

Foaming agents have been developed to improve control, but their use has not been widely adopted. Nozzles were developed specifically for dispensing foams. Research has shown that the decreased drift obtained is attributable more to the nozzle than the foam itself (Bouse et al. 1976).

Although many variables affect spray drift, it is clear that elimination of small droplets, especially those less than 100 um in diameter, is the fundamental solution to the drift problem. However, the biological effectiveness of the phenoxy herbicides decreases as droplet size increases and droplet density decreases. For example, McKinlay et al. (1972) found that increasing droplet size from 100 to 200 um with volume kept constant, required three times as much active ingredient, and when size was increased to 400 um, six times as much herbicide was needed to give equivalent biological effects. There are two factors that tend to make smaller droplets more effective. First, the leaf area contacted by a given volume of spray solution is greater when droplets are smaller. That may enhance absorption. Secondly, high herbicide concentrations localized in larger droplets may so damage the underlying cells that translocation to other tissues is reduced. In practice the lower effectiveness of larger droplets can be offset by increasing herbicide concentration of the spray solution or by increasing the total volume. Both increase costs.

Drift can be reduced when using conventional application equipment by taking advantage of the best combination of nozzle type and orientation, orifice size, pressure, and spray mixture. In addition, modern engineering developments permit reduction of droplets below 100 um diameter to near zero. The microfoil boom, for example, has nozzles placed in a boom shaped like an airfoil which minimizes turbulence at the point where droplets are formed. Primary droplets from microfoil nozzles are about twice the size of the orifice. Smaller satellite droplets are formed from thin filaments of spray between the primary droplets, but proper nozzle orientation will result in the capture of small droplets by large droplets in the smooth air behind each nozzle. When equipped with 0.013- and 0.028-inch nozzles, droplets of 800 and 1,700 um, respectively, are produced with a variation of only $\pm$ 200 um. Integrity of the droplet size range cannot be maintained at air speeds greater than 60 mph. Accordingly, the microfoil boom is used only on helicopters.

The microfoil boom is expensive to buy and is subject to clogging and other problems if not properly maintained. Nevertheless, it provides the best drift control available at this time. Other application systems are in the process of development (Stewart and Gratkowski 1976).

REDUCTION OF DRIFT THROUGH REGULATION

Many states have regulations designed to promote proper use, thereby reducing drift. In Arkansas (McKinlay et al. 1972), for example, sale of high-volatile esters of 2,4,5-T are prohibited except by written permission of the Director of the State Plant Board. Moreover, manufacturers must have a permit to sell any quantity more than one quart in size; invoices for such sales must be mailed to the State Plant Board within seven days of the sale. Sales of more than one quart may be made only to dealers or custom or private applicators who hold a current permit. Arkansas is divided into two zones. Zone 1 includes the cotton-growing area of the State, Zone 2 includes the remainder of the State. In Zone 1, 2,4,5-T may not be applied either aerially or by ground within 1/4 mile of susceptible crops at any time unless prior authorization is received. Moreover, low-volatile esters of 2,4,5-T may not be aerially applied between April 15 and October 1 within one mile of susceptible crops. In Zone 2, 2,4,5-T may not be aerially applied within 1/4 mile of susceptible crops at any time unless prior authorization is received. Both aerial and ground applications of 2,4,5-T may be made under restricted conditions of wind velocity, temperature, height of spray release pressure, spray volume, nozzle design and orientation, and proximity to dwellings.

In Oregon and Washington, the temperature, wind velocity, humidity, width of buffer strips, and other conditions are specified for 2,4,5-T spraying on forests.

In California, applications of 2,4,5-T are regulated by the Department of Food and Agriculture. Forest and rangeland use requires a plan of operation for the defined treatment area, a spill contingency plan, and a plan for sampling streams for possible contamination before a permit to conduct the spraying is granted. Written notice must be published in a newspaper that has general circulation within the proposed treatment area, and public comment received within 25 days after publication must be reviewed and evaluated. Property owners within 1/4 mile of the proposed treatment area must be notified by the permittee.

In Texas, wind speed, spray pressure or droplet size, and release height are regulated. Aerial applications of 2,4,5-T may not be made nearer than 4 miles upwind from a susceptible crop when windspeed is 7 to 10 mph.

The regulations in effect for Arkansas, Oregon, Washington, California, and Texas are representative of the type of regulatory control exercised by most states. Drift is widely recognized as a serious but largely correctable problem amenable to regulatory control. The important point is that applications of 2,4,5-T cannot be made by just anyone in any way he chooses, but must be made in compliance with recognized safety standards.

PART 2: THE BEHAVIOR AND FATE OF 2,4,5-T IN THE ENVIRONMENT

INITIAL DEPOSIT

In nearly all parts of the environment the highest levels of chemical residue occur immediately after application. The data in this section can be used to estimate exposure levels for all types of animals which feed in or enter areas shortly after application.

VEGETATION

Vegetation is the primary receptor of 2,4,5-T sprays. The amount of herbicide intercepted by vegetation varies with the rate and nature of the application and the type and density of the vegetation. Data from Altom and Stritzke (1972) show 33 percent of the herbicide application penetrated the overstory. Bouse and Lehman (1967) reported 19 to 22 percent penetration. These data suggest up to 80 percent of the spray is intercepted by overstory vegetation.

Norris et al. (1977) looked at the initial distribution of 2,4,5-T low-volatile esters in oil applied by helicopter to a mixed hardwood brush community in northwest Oregon. They found marked contrast in the concentration of herbicide shortly after application among various species which indicates the nature of the intercepting surface is also important (table 3). This particular area was re-treated 1 year later, and the results (table 3) show an increase in the initial herbicide concentrations in live blackberries (*Rubus sp.*), grass, and vine maple which reflects a general decrease in vegetation densities from the year before. The initial concentration on Douglas-fir (*Pseudotsuga menziesii*) is the same in both years because the individual trees sampled were growing in the open, and the density did not change from one year to the next. Plumb et al. (1977) reported initial herbicide concentrations of 95 and 92 ppm 2,4-D and 2,4,5-T respectively, in chamise (*Adenostoma fasiculatum*) immediately after a simulated aerial application of 3 lb/A each 2,4-D and 2,4,5-T in southern California (table 3).

Table 3--Phenoxy herbicide residues in vegetation

Herbicide	Location	Plant species	Application	Residue level ppm (days after application)	Reference
2,4-D	So. Calif.	Chamise	3 lb/A ae PGBE ester in water, simulated aerial application, May	95(0) 70(14) 69(29) 20(69) 16(146) 3.8 (379)	Plumb et al. 1977
2,4-D	Texas	Grass	1 lb/A ae 2,4-D amine in water, simulated aerial application, June	80(0) 70(7) 45(14) 30(28) 6(56) 1(112)	Morton et al. 1967
2,4-D	Sweden	Poplar	Glass house application, 2,4-D butoxyethyl ester in diesel oil	2300(1) 2500(3) 1800(9) 1300(37) 870 (365)	Eliasson 1973
2,4,5-T	Texas	Grass	1 lb/A ae PGBE ester in water, simulated aerial application	73(0) 2.1(42) 0.02(182)	Bovey & Baur 1972
2,4,5-T	Germany	Raspberry (fruits)	5.4 lb/A formulation not known, in water, foliage application from ground, June & July	16(0) 11.2(5) 3.4(15) 1.5(30) (by interpolation Table 2)	Olberg et al. 1974
2,4,5-T	Texas	Live oak (stem tips)	2 lb/A ae 2,4,5-T isooctyl ester in water, simulated aerial application, June	9.6(30) 0.7 (180)	Baur et al. 1969
2,4,5-T	Texas	Grass	2 lb/A ae 2,4,5-T isooctyl ester in water, simulated aerial application, June	7.0(30) 0.2(180)	Baur et al. 1969
2,4,5-T	Texas	Grass	0.5 lb/A ae 2,4,5-T butoxyethanol ester in water, simulated aerial application, June	48(0) 35(7) 10(14) 9(28) 7(56)	Morton et al. 1967
2,4,5-T	Texas	Grass	2 lb/A ae 2,4,5-T Butoxyethanol ester in water, simulated aerial application, June	205(0) 150(7) 50(14) 60(28) 25(56)	Morton et al. 1967
2,4,5-T	Oregon	Douglas-fir	2 lb/A ae, isooctyl ester in oil, helicopter application in early spring-first annual application	52(0) 11.1(30) 0.35(90) 0.47(180) 0.22(360) 0.0(720)	Norris et al. 1977
			Second annual application	52(0) 14.2(30) 0.10(90) 0.04(180) 0.0(360)	

(continued)

Table 3--Phenoxy herbicide residues in vegetation (continued)

Herbicide	Location	Plant species	Application	Residue level ppm (days after application)	Reference
2,4,5-T	Oregon	Vine maple	First annual application	10.6(0) 0.48(30) 0.28(90) 0.16(180) 0.48(360) 0.02(720)	ibid.
			Second annual application	23.2(0) 10(30) 0.10(90) 0.10(180) 0.02(360)	
2,4,5-T	Oregon	Grass	First annual application	114(0) 3.4(30) 0.58(09) 0.14(180) 0.12(360) 0.0(720)	ibid.
			Second annual application	140(0) 9.3(30) 0.21(90) 0.12(180) 0.0(360)	
2,4,5-T	Oregon	Blackberry (vines & foliage)	First annual application	45(0) 0.59(30) 0.05(90) 0.02(180) 0.03(360) 0.0(720)	ibid.
			Second annual application	165(0) 2.9(30) 0.01(90) 0.0(180) 0.0(360)	
2,4,5-T	So. Calif.	Chamise	3 lb/A ae, PGBE ester in water, simulated aerial application, May	92(0) 44(14) 32(29) 14(69) 2.9(146)	Plumb et al. 1977

Grass is an important component of both forests and range. Grass communities have potential for high herbicide concentrations because they are a relatively low-growing type of vegetation with a large surface-to-mass ratio. Bovey and Baur (1972) detected from 27 to 140 ppm 2,4,5-T on the day of application of 0.5 lb/A and 53 to 144 ppm from 1 lb/A applications in native or tame pasture grasses. Similar amounts using similar rates per acre of 2,4,5-T have been reported in other studies (Bovey et al. 1974, Bovey et al. 1975, Scifres et al. 1970, Morton et al. 1967).

Olberg et al. (1974), investigating 2,4,5-T residues in wild raspberry fruits (species not identified), reported that initial herbicide concentrations ranged from 0.7 to 3.3 ppm 1 hour after treatment with 5.4 lb 2,4,5-T per acre in tests conducted in 1972. Apparently similar applications in 1973 produced initial 2,4,5-T residues ranging from 7.9 to 22.2 ppm. Applications in both cases were by "backpack power sprayer." By contrast, Maier-Bode (1972) found only 1 ppm 2,4,5-T on unidentified wild berries in Sweden on the day of treatment by aircraft (table 3).

These various reports indicate initial phenoxy herbicide residues in vegetation can range up to about 220 parts per million for rates of application up to 2 lb/A. Proportionally higher residue levels may be expected for higher rates of application.

GROUND

The term ground used in this report includes both the mineral soil and any overlying organic layers such as the forest floor. Herbicide reaches the ground during application (that portion of spray material not intercepted by vegetation, or lost to the atmosphere) or later in the washing action of rain or leaf fall from treated plants. The distribution of spray material between the overlying organic layers and the mineral soil is obviously determined by the thickness of the organic layers. In forest environments, relatively thick organic layers occur, thus the residue levels in soil are much lower than on rice field levees where there is little or no organic matter.

Bovey and Baur (1972) determined the concentrations of the propylene glycol butyl ether esters of 2,4,5-T applied at 0.5 and 1 lb/A on five pasture and range sites in Texas immediately after treatment. Concentrations of 2,4,5-T ranged from 1 to 3 ppm from 0.5 lb/A applications and 3 to 5 ppm from 1 lb/A treatments in the surface 6 inches of soil. However, on areas with a heavy grass cover, 2,4,5-T at similar rates applied as the triethylamine salt never exceeded 0.1 ppm even when applications were made every six months for a total of five applications (Bovey et al. 1974, Bovey et al. 1975). Soils were sampled at 1 foot intervals to a depth of 4 feet. The bulk of the 2,4,5-T was found in the surface 6-inch layer of soil. Scifres et al. (1977) found less than 0.1 ppm of 2,4,5-T immediately after treatment in the surface inch layer in deep sand soils at three locations in central Texas. Rate of spray recovery averaged 92 percent on the open surface as determined by recovery of 2,4,5-T from mylar cards placed on the soil. In this study a heavy stand of coastal bermudagrass intercepted a large percentage of the 2,4,5-T before it reached the soil.

In other studies, Scifres et al. (1970) showed the influence of vegetation in reducing the amount of herbicide reaching the soil surface For example, grass cover, honey mesquite cover and grass--perennial ragweeds--honey mesquite cover reduced the concentration of herbicide reaching the soil by 42, 61 and 89 percent respectively. Norris et al. (1977) reported maximum soil residues of 2,4,5-T did not exceed 0.1 ppm in the forest floor due to interception of the 2,4,5-T by vegetation and forest floor litter.

In an arid environment Radosevich and Winterlin (1977), reported most of the 2,4-D and 2,4,5-T was intercepted by the woody (chamise) and herbaceous vegetation and litter with only 0.1 percent of the 2,4-D and 0.07 percent of the 2,4,5-T reaching the soil. Most herbicide was intercepted by the litter (>50%).

WATER

Herbicides can enter surface waters by direct application to stream surface, accidental drift from nearby treatment units, in overland flow during periods of intense precipitation, or by leaching through the soil profile. The magnitude and duration of the contamination which might occur from each of these processes is different. Direct application or drift to surface waters is likely to result in the highest concentrations of herbicide in the water, but the duration of entry is short, being largely restricted to the period of application. Therefore, organism exposure may be relatively intense but brief. If overland flow occurs, more moderate concentrations of herbicide could result in streams because stream discharge volumes are likely to be considerably greater than during periods of application. The duration of entry via overland flow would probably be relatively brief being restricted to periods of particularly intense precipitation. If herbicides enter streams by leaching, the concentrations are apt to be quite low, but the duration of entry could conceivably be considerably longer than for either direct application or the overland flow process.

Surface water on pastures and rangeland usually consists of ponds and lakes or moving streams. In forest areas, most surface water is in streams although lakes are common in some areas. Surface waters are avoided by spray equipment, but some contamination may occur incidental to treatment. 2,4,5-T may occur in small amounts in runoff water, however, if heavy rainfall occurs soon after treatment.

In impounded water it is possible, in an extreme case, to get concentrations of 2,4,5-T approaching 1 ppm (1 foot deep lake sprayed with 2 lb/A of 2,4,5-T by accident). However, 2,4,5-T is subject to both microbial and photochemical degradation and the concentrations would decline rapidly after treatment.

Norris and Moore (1971) reported monitoring studies done in the 1960's which showed concentrations of 2,4-D and 2,4,5-T were usually less than

0.01 ppm and seldom exceeded 0.1 ppm in streams adjacent to operational forest spray operations in Oregon. More recent operational monitoring shows the use of a "one swath" buffer is effective in substantially reducing or eliminating herbicide residues in streams (Norris 1978). Similar concentrations of 2,4,5-T would be found under rangeland conditions. Once in the stream, the 2,4,5-T is subject to rapid dilution by the flowing water and is not usually detected at downstream locations.

Occurrence of 2,4,5-T in runoff water has been studied under various conditions after application to pastures and rangeland. Concentration of 2,4,5-T was moderately high (0.4 to 0.8 ppm) in runoff water if heavy rainfall occurred immediately after treatment (Bovey et al. 1975). However, if major storms occurred 1 month or longer after herbicide application, concentration in runoff water was below 0.005 ppm. Dilution from surrounding watersheds is important in dissipation of the herbicide.

OFF-TARGET

Regardless of all precautions there is some degree of drift of 2,4,5-T from treated areas (Bode et al. 1976, Bouse et al. 1976, Goering et al. 1973, Maybank and Yoshida 1969). The main effect of herbicide deposition in nontarget areas is on sensitive vegetation. Some broadleaf crops are affected by extremely low concentrations of 2,4,5-T. Such concentrations would be difficult to detect in soil and water sources as well as vegetation. Visual symptoms of herbicide effects on sensitive plants are often useful indicators although they are sometimes confused with certain plant diseases.

Airborne spray particles are inevitably transported to some extent by air movement to nontarget areas. This can amount to 20 percent of the total spray volume, depending upon the type of nozzles and pressures and other spraying conditions (Maybank and Yoshida 1969). Under other conditions as much as 98 percent of the spray may be deposited within the target area. Smith and Wiese (1972) found that application of

2,4-D at 0.05 to 0.1 lb/A applied to cotton caused significant yield loss. The earlier the cotton was sprayed, the more severe was its damage. 2,4,5-T is less damaging than 2,4-D. Studies by Maybank and Yoshida (1969) indicated drift deposits of herbicide (0.04 lb/A approached those causing injury to cotton. Rates of 2,4-D and possibly 2,4,5-T at 0.5 lb/A or higher can potentially affect adjacent sensitive crops if precautionary application measures are not taken to prevent drift. Spray drift was discussed in more detail in part one of this chapter.

SUBSEQUENT DISTRIBUTION AND FATE

PLANTS - RESIDUES AND FATE

Persistence of 2,4,5-T in treated vegetation is of importance since parts of forage and crop plants may be consumed by man and animals or man may consume wildlife and livestock that have grazed treated areas. Human entry to treated areas may also cause some dermal exposure. Persistence of phenoxys may also be important for the desired phytotoxic effects on weeds and sometimes undesirable in that valuable vegetation may be injured.

Phenoxy herbicide residues decline with time in vegetation through the action of several processes, including volatilization, photochemical or biological degradation on leaf surfaces, weathering (rain washing, cuticle erosion), absorption and translocation, growth dilution, metabolism, excretion, and others. Most field studies only determine residue levels and do not determine the importance of specific residue reduction processes.

Herbaceous Vegetation

Morton et al. (1967) studied the disappearance of 2,4-D, 2,4,5-T and dicamba over a 3-year period from a pasture containing several herbaceous species. No important differences were found in persistence of different herbicides. Most experiments showed half-lives of 2 to 3 weeks after application in green tissue for all three herbicides. The half-life in grass litter was slightly longer (3 to 4 weeks). Shorter residual of herbicides in green tissues was attributed to dilution by growth. Rainfall was important in hastening herbicide disappearance.

Baur et al. (1969) applied 2 lb/A of the 2-ethylhexyl ester of 2,4,5-T alone and with 0.5, 1 and 2 lb/A of the potassium salt or isooctyl ester of picloram to pastures supporting infestations of woody plants. Recovery of 2,4,5-T acid and ester from woody and grass tissues was greatest when applied with picloram. Herbicide concentration in all treatments, however, was usually less than 10 and 0.1 ppm, 1 and 6 months, respectively, after application.

Bovey and Baur (1972) analyzed forage grasses from five locations in Texas with wide variation in grass species, soils, and climate. These areas had been treated with the propylene glycol butyl ether esters of 2,4,5-T at 0.5 and 1 lb/A. An average of 98 percent of the 2,4,5-T was lost from all treated areas six weeks after treatment. After 26 weeks, the herbicide levels in grass ranged from 0 to 51 ppb.

In two separate studies, Bovey et al. (1974, 1975) applied a 1:1 mixture of the triethylamine salts of 2,4,5-T and picloram at a total of 1 and 2 lb/A on pasture land in central Texas. Repeat treatments were made every six months to the same area for a total of five applications. Herbicide content of native grass was highest (28 to 113 ppm) immediately after spraying, degraded rapidly after each treatment, and tended to disappear before each new application was made. There was no accumulation of 2,4,5-T in soils or vegetation. Other investigators report similar results (Scifres et al. 1977, Norris et. al. 1977, Radosevich and Winterlin 1977).

A short-term deferred grazing period after 2,4,5-T application is indicated on the herbicide labels for dairy animals (6 weeks) and meat animals (2 weeks) before slaughter. This deferred period acts as a safeguard to prevent herbicide residues in meat and milk products. From a range-management point of view, deferred grazing after herbicide treatment is important for recovery of desirable forage species once suppression by weeds competition is reduced by spraying. The deferred grazing period will vary according to the grazing system employed; however, five months deferment is usually desirable. This later deferral is to gain maximum benefit from the cultural practice, not to protect animals or to reduce residues in meat or milk.

2,4,5-T residues in raspberry fruits in European forests present a peculiar situation. Based on reports by Olberg (1973) and Olberg et al. (1974), it appears that 2,4,5-T applied at 5.3 lb/A in two formulations in June and July, caused relatively fast leaf wilt, but green berries continued to ripen and became "conspicuously large and beautiful."

Residue levels were determined by methods specified by the German Research Society (not available for evaluation) in fruits picked at various times between 0 and 41 days after application. The results present a confusing picture. Initial residue levels were markedly different in the 2 years of the study. First year results with one formulation show a four-fold decrease in residue level in 41 days but virtually no change in residue level over the same period with a second formulation. The second year, initial residue levels were much higher than the first year by substantial margin. These levels declined relatively quickly, however, with a mean half-life of 8.6 days for the first 15 to 17 days after treatment. There was a marked reduction in the rate of decrease after that time (table 3). By the end of the measurement period, which ranged from 29 to 41 days on different plots, residue levels varied from 0.4 to 2.2 ppm. These levels are substantially greater than the 0.05 ppm residue level permitted in Germany. The results are confounded to some degree by apparent 2,4,5-T residues in untreated fruits. One control set had no detectable levels of 2,4,5-T, but the other three contained residues ranging from 0.14 to 0.6 ppm. The successful development of the fruit after application makes one wonder about the overall effectiveness of the treatment. Some modification of formulation carrier or technique of application might accomplish more complete early season control such that treated fruits do not ripen. As a result of these studies, the season of application of 2,4,5-T in forests nurseries is restricted to that period before fruit-set or after fruit harvest.

Woody Vegetation

Baur et al. (1969) found most of the 2,4,5-T applied at 2 lb/A as the 2-ethylhexyl ester to live oak disappeared in 6 months. However, small amounts, both the acid (0.09 ppm) and ester (0.23 ppm) of 2,4,5-T could be detected 6 months after application. More 2,4,5-T was found in live oak tissue at 1 and 6 months from the top of the plant than the middle and lower stem due to the top portion intercepting more spray initially than lower regions. More 2,4,5-T was found in live oak treated with a combination of 2,4,5-T and picloram than treated with 2,4,5-T alone at equivalent rates.

Brady (1973) indicated radioactive 2,4,5-T persisted three to seven times as long in treated woody plants as in forest soils. The half-life of 2,4,5-T ranged from 5.5 to 12.4 weeks in several southern woody species. All species decarboxylated 2,4,5-T releasing $^{14}CO_2$ with no significant difference between species or doses. After 30 days over 90 percent of applied 2,4,5-T was lost from chamise brush (Radosevich and Winterlin 1977).

Plumb et al. (1977) made a simulated aerial application of 2,4-D and 2,4,5-T as the PGBE ester at a rate of 3 lb/A ae each to a 3 year-old stand of chamise in southern California. They report 2,4,5-T and 2,4-D had a half-life of about 17 and 37 days, respectively, in this vegetation. The rate and extent of decline of these herbicide residues were not as great as is noted in some other studies, very likely because the site was very dry. Plant moisture levels, which were very low at the time of application (about half of normal), declined to less than 30 percent 9 weeks after the application, largely eliminating plant metabolism of the residues (table 3). About 3 ppm 2,4-D and 2,4,5-T were present in the dead dry vegetation 1 year after application. Sprouts from the treated plants did not show formative effects but did contain 0.27 ppm 2,4-D and 0.31 ppm 2,4,5-T one year after application. These plant parts were not present at the time of applications, indicating these residues resulted from the translocation of chemical from treated portions of the plant.

Norris, et al. (1977) determined residues of 2,4,5-T in four species of forest vegetation after two successive annual applications of herbicide (4 lb/A ae as isooctyl ester applied in diesel oil by helicopter in March). Their results show a sharp decrease in herbicide concentration the first month after application (table 3). The mean half-life of 2,4,5-T for all species was about 2 weeks after both the first and the second application. The rate of residue decline slowed after 3 months. One year after application, residues ranged from 0.48 ppm in vine maple foliage to 0.07 ppm in blackberry runners and foliage. 2,4,5-T residues were below detectable limits (0.01 ppm) in all species except vine maple 2 years after the first application. The rate of decline of 2,4,5-T residues in vegetation after the second application was similar to the first except that 1 year after the second application, no detectable residues were present in any of the sprayed vegetation. In this case, at least, two successive annual applications of 2,4,5-T had no appreciable effect on the persistence of the herbicide in four different kinds of vegetation.

Eliasson (1973) applied butoxyethyl ester of 2,4-D to young aspen in a glass house experiment and found a decrease in herbicide residue level with time, despite the fact an extremely high concentration of herbicide was present initially, and after 9 days more than half the sprayed leaf tissue was dead (table 3).

Processes of 2,4,5-T Disappearance in Plants

Basler et al. (1964) and Norris and Freed (1966a,b) established that 2,4-D and 2,4,5-T are decomposed in excised leaves from woody plants. Morton (1966) showed that approximately 80 percent of the 2,4,5-T absorbed by mesquite leaves was metabolized after 24 hours. Numerous other investigations have also shown the importance of metabolism in detoxification and loss of phenoxy herbicides within many plant species.

Leaves and stems of plants are main receptors of foliar-applied herbicides. Aside from their function in decarboxylation, breakdown, and conjugation of the herbicide, leaves and plant parts may abscise from the plant and fall to the soil where the tissue and any residual herbicide is subject to weathering and decay. Aerial parts of plants may also be removed by mowing machines or clipped and consumed by grazing animals. If the herbicide does not kill or stop growth of the plant (many grasses), the herbicide will be diluted by the growth and biomass accretion of the organism.

On plant surfaces, phenoxy herbicides are lost by photodegradation and volatilization in a manner similar to loss from soils. Rainfall is also reported as an important means of accelerating herbicide loss from litter and plant surface (Bovey et al, 1974, Bovey et al. 1975, Eliasson 1973, Morton et al. 1967).

SOILS - RESIDUE AND FATE

Research Monitoring

As indicated from several studies (Bovey and Baur 1972, Bovey et al. 1974, Bovey et al. 1975, Scifres et al. 1977, Norris et al. 1977, Radosevich and Winterlin 1977) under normal application practices, initial levels of 2,4,5-T in soils are usually low and disappear relatively rapidly. In field studies, DeRose and Newman (1947) found 2,4,5-T at 10 lb/A persisted 93 days after application. The investigators concluded persistence was determined by soil microbial activity since 2,4,5-T persisted longer in autoclaved than nonautoclaved soil. Other factors affecting disappearance of 2,4,5-T in soil include soil temperature, leaching, and soil organic matter. Generally, those conditions which favor microbial activity will favor more rapid decomposition of 2,4,5-T.

In 1954, Warren (1954) studied the leaching and rate of breakdown of several phenoxy herbicides in a fine sand, silt loam, and "old" and "new" muck soil types using crabgrass as a bioassay species. He found 2,4-D ester, 2,4,5-T amine and silvex amine readily moved in sandy soil, but little in mineral soils or mucks. Esters of silvex and 2,4,5-T were resistant to leaching in all soils with some movement in sand only. The ester and amine formulations of 2,4,5-T disappeared in two weeks from old muck and in four weeks from new muck and silt loam soil. In sand, 2,4,5-T amine activity dissipated before eight weeks, but some activity of the 2,4,5-T ester occurred after eight weeks. Silvex tended to be more persistent than 2,4-D and 2,4,5-T with some activity of the ester formulation still present after eight weeks in the sand and old muck soils.

More recent research, using gas chromatographic analytical techniques has generally confirmed the results of earlier investigators. Altom and Stritzke (1973) reported the average half life of the diethanolamine salts of 2,4-D, dichlorprop, silvex, and 2,4,5-T were 4, 10, 17, and 20 days in three soil types. Except for 2,4-D the rate of disappearance of the other phenoxys was faster in soil from Oklahoma grasslands than forest. Lutz et al. (1973) studied the movement and persistence of picloram and 2,4,5-T (2 and 4 lb/A) on a North Carolina watershed which averaged a 27 percent slope. Approximately 60 percent of the picloram and 90 percent of the 2,4,5-T disappeared in 15 days. Most of the 2,4,5-T was found in the top 3 inches of soil with no movement of 2,4,5-T beyond 12 in. downslope. In Texas, Bovey and Baur (1972) applied an ester of 2,4,5-T at 0.5 and 1 lb/A to soils at five locations. After six weeks the 2,4,5-T had essentially disappeared from all locations. Soils were sampled to a depth of 3 feet. Similar results were obtained by other workers at other geographical locations (Scifres et al. 1977, Norris et al. 1977, Radosevich and Winterlin 1977).

Plumb et al. (1977) reported on the persistence characteristics of 2,4,5-T applied at 3 lb/A to a chamise site in southern California. Residue levels immediately after application were not determined, but based on residues present 14 days after application (0.9 ppm), 2,4,5-T showed a half-life of about 19 days for the period 14 to 29 days after application (table 4). The rate of degradation changes with time, however. Approximately 1 year after application, the residue level was about 0.05 ppm.

Norris et al. (1977) determined 2,4,5-T residues in forest floor and soil after two successive annual applications of herbicide at 2 lb/A ae applied as the isooctyl ester in diesel oil by helicopter in March. The study area was a cool, moist site in western Oregon (table 5). The rate of decline in 2,4,5-T levels in forest floor after the first application at this site was slower than at the hot, dry site in southern California (Plumb et al. 1977), which may reflect the importance of volatilization and photodecomposition on the loss of phenoxy herbicides from exposed soil surfaces. The rate of loss of 2,4,5-T was quite rapid the first 30 days after the second application, which indicates good adaptation of the microorganisms after the first application. One year after application, residue levels in forest floor were about 0.75 percent of the amount of herbicide originally applied. These data show the strong tendency of forest sites to dissipate 2,4,5-T. Residues were largely confined to the top 6 in. of soil.

Survey Monitoring

Wiersma et al. (1972) reported on analysis of soils for 2,4-D and other

Table 4--Average concentration of 2,4-D and 2,4,5-T in composite soil samples collected from 3 soil depths from a chamise site treated with 3 lb/A ae of each herbicide in southern California (Plumb et al. 1977)

Days after treatment	2,4-D Soil depth (in.)			2,4,5-T Soil depth (in.)		
	0-4	4-8	8-12	0-4	4-8	8-12
	ppm					
14	1.16	0.16	0.09	0.88	0.06	0.03
29	0.71	0.07	0.05	0.53	0.02	0.02
69	0.22	0.02	0.02	0.29	0.01	0.03
146	0.11	0.02	0.01	0.21	0.02	0.01
379	0.04	0.02	0.02	0.05	0.03	0.03

Table 5--2,4,5-T in forest floor and soil after two successive annual applications, 2 lb/A ae. Herbicide was applied as isooctyl ester by helicopter in March (Norris et al. 1977)

	Months after application					
	0	2	3	6	12	24
	First application					
Forest floor (mg/m^2)a/	35.7	40.6	12.1	3.9	1.7	0.7
soil (ppm)[a]						
0-6 in	0.007	0.015	0.077	0.016	0	0
6-12 in	0	0.003	0	0	0	0
12-18 in	0	0	0	0	0	0
18-24 in	0	0	0	0	0	0
	Second application					
Forest floor (mg/m^2)b/	137.4	9.7	12.5	4.1	1.5	-c/
soil (ppm)[b]						
0-6 in	0.008	0.002	0.003	0.002	0.002	-
6-12 in	0.002	0.001	0	0	0	-
12-18 in	0	0	0	0	0	-
18-24 in	0	0	0	0	0	-

a/ Data for 0,1,3,6 and 12 months are for 9 plots, data for 24 months are from 3 plots.

b/ Data are for 6 plots which received second application.

c/ No samples were collected 24 months after the second application.

chlorophenoxy herbicides by the National Pesticide Monitoring Program staff in 1969. 2,4-D was the only herbicide detected (2,4-D was found in 1.6 percent of 188 samples analyzed with a mean residue level of 0.01 ppm).

In 1970, the National Soils Monitoring Program of the EPA (Carey et al. 1973) sampled soils treated with pesticides in the Corn Belt (an area which uses about one-fourth of the 2,4-D in the U.S.). No 2,4-D or other phenoxy herbicides were detected in soil or crop samples collected, although several insecticides were found. These data indicate that 2,4-D and related phenoxy herbicides are not accumulating in the environment from current patterns of use.

Effects of High Rates of Application or Persistence

Some people are concerned that residues of 2,4-D and 2,4,5-T left in soils in Vietnam might destroy subsequent crops. Early work by Craft (1949), DeRose and Newman (1947) and many others indicated that 2,4-D and 2,4,5-T when applied even at high rates usually do not persist from one growing season to another, due largely to microbial breakdown. Work by Bovey et al. (1968) in Puerto Rico indicated that corn, sorghum, wheat, rice, soybeans, and cotton could be grown in soils without reduction in fresh weight of the crops 3 months after the application of a 1:1 mixture of the -butyl esters of 2,4,-D + 2,4,5-T at 24 lb/A. Similar results were obtained for a 2:2:1 mixture of 2,4-D + 2,4,5-T + picloram at 15 lb/A (except for soybeans, which required 6 months for the phytotoxic effect to disappear). The longer residual effect on soybeans is probably due to picloram because of its greater persistence in soils.

Blackman et al. (1974a & b) reported on recent studies in Vietnam which indicate sensitive crops can be safely grown 4 to 6 months after single applications of the n-butyl esters of 2,4-D and 2,4,5-T at rates up to 12 lb/A. The authors indicate the dosage of herbicides in their experiments was considerably higher than would occur in spraying forests or mangroves since their materials were applied directly to bare soil and were not intercepted by herbaceous and woody vegetation. Young et al. (1974a) incorporated a 50:50 mixture of the n-butyl ester of 2,4-D and 2,4,5-T into a soil trench in Utah at the rate of 1,000 2,000, and 4,000 lb/A. After 440 days, 89, 85 and 83 percent respectively of the herbicide was degraded. The rate of loss of the herbicide was rapid considering the low temperatures that prevailed for 7 months during the experiments.

In another study, Young et al. (1974b) reported on the effect of massive doses of 2,4-D and 2,4,5-T sprayed on an area at Eglin Air Force Base in Florida. About ninety-two acres received 1900 lb/A 2,4-D and 2,4,5-T in 1962 to 1964; a second area received 1200 lb/A in 1964 to 1966, while a third area received 340 lb/A of 2,4-D and 2,4,5-T from 1966 to 1970. Chemical analyses of soil cores collected in 1970 from the treated areas showed a maximum concentration, 8.7 ppb of either herbicide, indicating the herbicide had essentially disappeared.

In greenhouse studies using lysimeter columns, O'Connor and Wierenga (1973) found 2,4,5-T degraded rapidly especially in soils previously treated with the herbicide. Biological detoxification of 2,4,5-T applied at 40 and 80 ppm occurred in 43 to 85 days depending upon pretreatment or concentration. The herbicide was not leached below 14 in. in a 60 in. lysimeter. The rates of 2,4,5-T used were 30 to 60 times that used in normal practice.

The Effects of Repeated Treatment on Persistence

Repeat treatments 1 or 2 years following the original treatment are sometimes necessary to control certain brush species with phenoxy herbicides. In two separate studies in Texas, Bovey et al. (1974, 1975) found that 2,4,5-T did not accumulate in soils when applied five times at 0.5 and 1 lb/A every 6 months on the same area. The average concentration did not exceed 95 and 144 ppb, respectively, even when sampled immediately after the last treatment. Most of the herbicide was confined to the surface 6 in. of soil and usually disappeared by the time of retreatment. Soils were sampled at various intervals to a depth of 48 in. The 2,4,5-T was applied as the triethylamine salt in a 1:1 mixture with picloram. In the Oregon forest environment, Norris et al. (1977) reported that two successive annual applications of 2,4,5-T did not increase the persistence of 2,4,5-T. Residue disappearance was at least as rapid after the second application as after the first.

The work in Florida reported by Young et al. (1974a) (see previous section on "High Rates") is an excellent example of rapid disappearance of 2,4-D and 2,4,5-T from frequent repeated applications of massive doses of these herbicides to the soil. In an extensive review of the literature, House et al. (1967) found that 2,4-D and 2,4,5-T essentially disappear from soils a few months after application, regardless of rate applied.

Effects of Pretreatment on Persistence

The microbial degradation of phenoxy herbicides has been thoroughly investigated under laboratory and field conditions (Audus 1964). In field studies, Newman et al. (1952) found that 2,4-D was reduced more rapidly in soils in which it had been decomposed previously. 2,4,5-T disappeared no more rapidly on retreatment than in Duffield silty clay loam. More recent work by O'Connor and Wierenga (1973), however, indicated that 2,4,5-T in lysimeter studies degraded more rapidly following the third herbicide irrigation or treatment presumably because of the presence of a larger microbial population capable of degrading 2,4,5-T than was present at a second irrigation.

Audus (1964) used the term "enrichment" to describe bacterial proliferation in response to a new substrate. Once enriched with a new bacterial population in the soil, the organisms will continue to metabolize the herbicide at a rapid rate so long as the herbicide continues to be supplied to it. If the enriched soil is left for considerable time (60 days) without supplying herbicide, the adapted organisms turn to alternative substrates in the soil, although the state of enrichment is partially retained for long periods in the absence of herbicide.

Processes of Disappearance in Soil

Microbial Decomposition

Persistence of 2,4,5-T in soils is usually two to three times longer than 2,4-D (DeRose and Newman 1947), and very few organisms have been identified as having the ability to decompose the 2,4,5-T molecule (Aly and Faust 1964). Newton (1971) calculated (from studies on the kinetics of degradation by microorganisms) that 2,4,5-T has a half-life of seven weeks in the forest floor. Blackman et al. (1974a & b) noted that in tropical soils, phytotoxic residues from 27 lb/A application of the n-butyl esters of 2,4-D and 2,4,5-T disappeared within 4 weeks. Leopold et al. (1960) found that increasing chlorination of phenoxyacetic acid decreased its water solubility while increasing its adsorption onto activated carbon and organic matter, thus making it less available for microbial degradation. Moreover, Thiegs (1962) noted, from reviewing the literature, that 2,4,5-T was less <u>susceptible</u> to attack by microorganisms because the aromatic nucleus of halogenated phenoxyalkyl carboxylic acids and phenols are more biologically inert in compounds containing the halogen (chlorine) in a position meta (the 5 position) to the phenolic hydroxy.

Investigations by Winston and Ritty (1972) and Reigner et al. (1968) indicated that <u>both</u> 2,4-D and 2,4,5-T are decomposed to form carbon dioxide, inorganic chlorides, and water; chlorophenols are not end-products of this decomposition. Reinhart (1965) provided supporting evidence. The upper half of a 22-acre timbered watershed in northern West Virginia was logged and then 11 acres were treated with 10 lb/A 2,4,5-T ester to kill all vegetation. No odor contaminants (phenols or catechols) were found in numerous water samples taken from the stream draining the treated watershed.

Plant Uptake and Metabolism

Weed and crop plants also absorb and detoxify herbicides by interception of the spray by leaves and stems and uptake of the herbicide from the soil through roots. The fate and detoxification processes of phenoxy herbicides by higher plants will be discussed later. Appreciable loss of herbicide through action of higher plants will occur (Morton et al. 1967). In some cases herbicides are also retained within the tissues of the plant, thereby delaying decomposition.

Chemical Decomposition

Phenoxy herbicide may be degraded by chemical processes in the absence of living organisms. Decomposition may occur by oxidation, reduction, or hydrolysis (Weber et al. 1973). For example, the isopropyl and butyl esters of 2,4,5-T undergo rapid hydrolysis to the acid form in moist soils. Smith (1976) reported less than 20 percent of the esters remained in one soil and none in three others 24 hrs after application.

Photodegradation

Herbicides applied to plant and soil surfaces are subject to decomposition by sunlight. Numerous investigators have shown photolysis of phenoxy herbicides under laboratory and field conditions (Crosby 1976). Crosby and Wong (1973) irradiated aqueous solutions of 2,4,5-T with ultraviolet light and identified the products involved. In aqueous solution, cleavage of the ether bond and replacement of the ring chlorines by hydroxyl and hydrogen occurred. The major products were 2,4,5-trichlorophenols and 2-hydroxy-4,5-dichlorophenoxyacetic acid; 4,6-dichlororesorcinol, 4-chlororesorcinol, 2,5-dichlorophenol and a dark polymeric product. TCDD was not detected among the photodecomposition products. They concluded sunlight can be an important factor in environmental degradation of 2,4,5-T.

Some researchers have shown that 2,4-D, MCPA, 2,4,5-T, and silvex are stable under dry conditions, whereas others have shown the opposite effect (Crosby 1976). Under field conditions, however, herbicides on leaf and soil surfaces are subjected to alternate wet and dry periods due to intermittent rainfall and dew. Baur et al. (1973) and Baur and Bovey (1974) reported considerable loss of dry preparation of 2,4,5-T and 2,4-D from petri dishes under long-wave ultraviolet light (356 nm).

Thermal Loss

Temperatures on the soil surface frequently exceed 140°F (60°C) under summertime conditions. Baur et al. (1973) found significant loss of 2,4,5-T (55%) as the free acid exposed to 60°C but no loss at 30°C after 7 days. The potassium salt of 2,4,5-T adjusted to pH 7.0 showed significant loss (30%) both at 30 and 60°C after 7 days exposure. Baur and Bovey (1974) found exposure of dry preparations of 2,4-D to 60°C resulted in 50 percent loss of the herbicide in one day. In the field it is likely that herbicide not adsorbed or absorbed by soil and plant material would be subjected to rapid ultraviolet and thermal degradation.

Adsorption

2,4,5-T is an organic acid with a pKa of 2.84 and may occur either as an anion or an undissociated molecule in the normal pH range which occurs in field situations (Frissel 1961). Negatively charged anionic herbicides are not readily adsorbed to negatively charged soil colloids (Weber et al. 1973).

Weber et al. (1965) indicated 2,4-D adsorption in soils is due to organic matter, iron and aluminum hydrous oxides, or possibly diffusion into fine pores of inert material. However, in most cases the amounts of herbicide bound to positively charged soil colloids is small (Weber et al. 1973). Weber (1972) studied the relative adsorption of 14 different herbicides by soil organic matter. The acidic herbicides dinoseb, picloram, 2,4-D, and dicamba were adsorbed in relatively low amounts compared to basic and cationic herbicides and the amount adsorbed was inversely related to the water solubilities of the acidic compounds. 2,4,5-T will behave similarly.

O'Connor and Anderson (1974) indicate that organic matter is an important contributor to 2,4,5-T adsorption and in some soil is the only adsorbent of significance. Oxides of Fe and Al did not contribute to 2,4,5-T adsorption in the soils they studied.

Since 2,4,5-T is poorly adsorbed by soils and is relatively water soluble (238 ppm at 20-25°C), some movement can be expected in the soil solution. Available data, however, indicate that the phenoxy herbicides are usually found in the top layers of soil (0 to 6 inches) and thus pose no hazard through leaching into the subsoil or groundwater. Movement of the phenoxys into surface runoff and groundwater is discussed in the following section.

WATER - RESIDUES AND FATE

Streams and Surface Runoff

Research Monitoring

2,4,5-T can enter surface water through direct application, drift, or leaching. These processes have been intensively studied in connection with both experimental and operational applications of 2,4,5-T.

Entry To Streams Via Leaching

On a relative scale, 2,4,5-T is considerably more mobile in the soil than many pesticide materials. On a real scale, however, its movement is small relative to the distance from treated areas to streams (Harris 1967, 1968). Numerous investigators have shown herbicide persistence and mobility in the soil are inversely correlated with organic content.

Many forest soils are typically high in organic matter. Laboratory studies by O'Connor and Wierenga (1973), Edwards and Glass (1971), Lutz et al. (1973), Weise and Davis (1964), Helling (1971 a,b,c) and field studies by Norris, et al. (1977), Plumb et al. (1977), and Bovey and Baur (1972) support the hypothesis that leaching is not an important process for transporting significant quantities of 2,4,5-T to streams.

Entry to Streams Via Overland Flow

This process requires overland flow of water, a phenomenon hydrologists report is relatively uncommon on most forest land. The infiltration capacity of forest floors and soils far exceeds most rates of precipitation except for areas in which soils are badly compacted, are water repellant, or have no surface protection by vegetation. Infiltration capacities in excess of 40 in./hr are not uncommon in many forest environments. In rangeland and agricultural situations, however, this may not be true, and some overland flow may occur. That is not to say that increased outflow of herbicide from treated watersheds does not occur with heavy rains, but that the process in this outflow is more likely to involve mobilization of surface residues from an expanding stream network close to the original stream channel rather than by what is usually viewed as overland (sheet) flow.

Trichell et al. (1968) investigated the loss of 2,4,5-T, dicamba, and picloram from bermudagrass and fallow plots of 3 and 8 percent slopes, using gas chromatographic and bioassay detection techniques. When determined 24 hours after application of 2 lb/A, a maximum of about 2, 3 and 5 ppm of picloram, 2,4,5-T, and dicamba, respectively, were found in runoff water after 0.5 in. of simulated rainfall. Losses of dicamba and picloram were greater from sod than fallow plots, while 2,4,5-T losses were about equal. Four months after application, picloram, 2,4,5-T, and dicamba concentrations in runoff water had diminished to 0.03, 0.04, and 0 ppm, respectively. The maximum loss from the treated area for any herbicide was 5.5 percent with an average of approximately 3 percent.

Edwards and Glass (1971) studied runoff of 2,4,5-T and methoxychlor in Ohio for more than 1 year after application of 10 and 20 lb/A respectively. A total of 5.5 g (0.05%) and 0.8 g (0.004%) of 2,4,5-T and methoxychlor was lost from the treated area in 14 months. The bulk of 2,4,5-T removed in runoff water took place the first 4 months after application and more than half of the loss occurred the first month after treatment. Loss of methoxychlor was relatively uniform and low for the 14-month period from each runoff event.

In North Carolina, Sheets and Lutz (1969) studied the movement of 2,4-D, 2,4,5-T, and picloram from established watersheds in 1967, 1968, and 1969. The watersheds of Halewood clay loam soil supported herbaceous and small woody plants and were unique in that the slope was 35 to 40 percent. Herbicide rate was 2 and 4 lb/A with all herbicides applied as the salt formulations and one ester formulation of 2,4,5-T. In some studies, herbicide could not be detected in runoff water.

Highest concentrations of the herbicide in surface runoff water at the base of small plots were found in 1969 when the application rate was 4 lb/A. Samples taken after the first storm causing significant runoff contained 1.8, 2.7, and 4.2 ppm for 2,4-D, 2,4,5-T, and picloram, respectively. In 1968, concentrations in surface runoff at the base of small plots were 1.2, 0.6, and 0.3 ppm for 2,4-D, 2,4,5-T, and picloram, respectively, the first rain after application. Thereafter, concentrations decreased rapidly. Total removal in runoff from treated plots amounted to 0.04, 0.01 and 0.01 percent of 2,4-D, 2,4,5-T and picloram, respectively.

The investigators indicated that although the concentrations of herbicide in water at the base of surface runoff plots within the watershed was high immediately after application, the levels in water from the flume at the base of the larger watershed were usually below the limits of detection. There was about a four-fold dilution with surface water from untreated land when one-fourth of each watershed was treated. When runoff was low, subsurface flow further diluted surface water and herbicide movement was retarded by adsorption to clay, soil organic matter, and decomposition by soil microorganisms. The authors concluded that low concentrations of 2,4-D, 2,4,5-T, and picloram may appear in runoff water from watersheds sprayed at rates needed for herbaceous and woody plant control. Concentrations in water vary directly with rate of application, percent of the area sprayed, and time, duration, and intensity of the storm.

Bovey et al. (1974) sprayed a 1:1 mixture of the triethylamine salts of 2,4,5-T + picloram at 1 lb/A every 6 months on a native grass watershed for a total of five treatments. Plant "wash-off" was the main source of herbicide detected in runoff water. Concentrations of both herbicides was moderately high (0.4 to 0.8 ppm) in runoff water if 1.5 in. of simulated rainfall was applied immediately after herbicide application. If major storms (natural) occurred 1 month or longer after herbicide treatment, concentrations in runoff water was below 0.005 ppm.

Direct Application or Drift to Surface Waters

Direct application or drift is the principal process by which aerially applied 2,4,5-T used in the forest enters streams. Patric (1971) and Norris and Moore (1971) provide useful compilations of studies of herbicide entry to forest streams. The following paragraphs describe and discuss results of studies of herbicide monitoring for stream contamination in connection with the operational use of phenoxy herbicides in forest and range sites.

Norris (1967) reporting research done by Norris, Newton, Zavitkovski, and Freed, presented data on herbicide residues in streams from several watersheds in Oregon forests treated with 2,4-D, 2,4,5-T or a combination of the two herbicides. All treatments were low volatile esters in diesel oil or water applied by helicopter at rates ranging from 1 to 3 lb/A.

The results show some herbicide is present in nearly every stream which passes through, or is adjacent to, treated areas. Maximum concentrations occurred during or shortly after application and were in the range from 0.001 ppm to 0.13 ppm. With the exception of marshy areas, highest concentrations and longest persistence occur when no provisions were made to avoid direct application to stream surfaces.

The time required to return to nondetectable levels (0.001 ppm) varied with the nature of the area treated and the maximum herbicide concentration observed. Times ranging from less than 1 hour to as much as 4 days have been noted with less than 1 day required in most instances. Norris, Newton, Zavitkiski, and Freed (Norris 1967) also noted a rapid decrease in herbicide concentration with downstream movement. Sampling in an estuary receiving waters from a large forest area which included numerous herbicide treatment areas, showed no detectable phenoxy herbicides (less than 0.001 ppm) in the water.

Through the use of buffer strips and careful attention to details of application, phenoxy herbicide concentrations in forest streams will seldom exceed 0.01 ppm and will not persist for more than 24 hours.

A recent review done for the Environmental Protection Agency by Newton & Norgren (1977) covers most of the important research and considerations involved in the protection of water quality when using silvicultural chemicals. One of the main conclusions is that an ample margin of safety can be easily maintained with very limited untreated buffer strips and the use of positive placement application techniques. The authors' second highest pollution-control priority (after the reduction of the potential for injury to aquatic systems with insecticides) is the maintenance of forest productivity in streamside buffer strips. They suggest that phenoxy herbicides can be used effectively and safely in these areas. The maximum untreated buffer strip recommended when using herbicides is 200 feet for picloram applications during periods of potential heavy rainfall. A buffer width of 1/2 the effective swath width from the center line of the nearest treatment swath is recommended for all phenoxy herbicides. This is based in part on Gravelle's (1976) data, which indicate that important gains to be made from buffer strips are limited to the first 50 feet from the edge of the swath. Beyond 50 feet there is a very low incidence of deposit which varies little with additional distance.

The USDA Forest Service has used 2,4,5-T for approximately 25 years. During this time, forest managers have actively sought to improve application technology including drift control and positive placement of the chemical. Refinements in technology and careful prespray planning can, and have, eliminated excessive 2,4,5-T residues in water. Levels of 2,4,5-T exceeding 0.01 ppm are seldom, if ever, encountered. Levels over 0.001 ppm are rare, and, even then, do not usually last for more than a few hours.

Of all Forest Service water samples collected in Oregon during the last 5 years, only two contained herbicide residues greater than 0.01 ppm. Both instances were traced and found to result from contaminated samples due to improper sample handling. However, even these two samples showed levels of only 0.01 and 0.013 ppm. The first 4 years of samples were taken where 100-foot buffers were used for major streams. The data from the past year came from areas where 200-foot buffer strips were used. There has been no significant contamination with either buffer strip. Thus, it appears there is no need to use buffer strips wider than 100 feet. Actually, the evidence suggests the width could be reduced.

Norris (1967, 1968) looked for the long term entry of 2,4-D and 2,4,5-T into forest streams draining areas receiving these herbicides. In one case, 11 streams in western Oregon were monitored immediately below treatment areas on a regular basis for 9 months after application. In all cases, once the initial stream contamination had declined to nondetectable limits (0.001 ppm in 3 to 72 hours), no further herbicide residues were detected. In a second case, two other watersheds in western Oregon were studied. In one, the treatment area bordered a stream for more than 1.9 miles extending from 200 to 400 yards upslope from the stream. 2,4-D and 2,4,5-T were applied at 1 lb/A ae each as low-volatile esters in oil in the spring. The second area had 25 different treatment areas totalling 395 acres in a 2800-acre watershed which received the same treatment. In both cases, streams were sampled to detect the movement of herbicide from treated areas to the stream, during the first storms of the fall which raised stream levels. No residues were found.

In a midwestern forest, Lawson (1975) sampled stream water during a rising hydrograph to look for storm-induced herbicide runoff after treating two 1.5 acre watersheds on three successive years at a rate of 4 lb/A 2,4,5-T in diesel oil by backpack sprayer. The sampled streams are not perennial streams and flow only in connection with significant storm events. 2,4,5-T residues in water to 2.2 ppm were detected in water collected in connection with the first runoff event which occurred 17 days after application. Less than 0.2 ppm 2,4,5-T was detected in the perennial stream which receives storm runoff from this area. Barely detectable levels of 2,4,5-T were found in samples collected with the next runoff event approximately 7 weeks after application. Subsequent storms did not produce detectable 2,4,5-T residues. These results should not be interpreted as true herbicide runoff in the sense of overland (sheet) flow. It appears more likely to be a case of herbicide mobilization from the bottoms of stream channels which were dry at the time of treatment. No herbicide residues were detected in samples collected during runoff events after either the second or the third application. These latter results are difficult to interpret, but may suggest rapid decomposition of the herbicide by microbial populations adapted to the use of 2,4,5-T after the first application. In any case, it is clear that in this Arkansas forest situation, significant movement of herbicides from treated areas to perennial streams did not occur.

In a similar forest type in Oklahoma, Igleheart et al. (1974) measured 2,4,5-T residues in water collected from streams immediately below four areas treated with 2,4,5-T at 2 lb/A applied by helicopter in May and June. Treated areas ranged in size from 247 to 2000 acres in areas where 20 to 100 percent of the watershed was treated. The results are similar to those of Norris (1967).

In eastern forests, Reigner et al. (1968) used odor tests to look for phenoxy herbicides in streams from four areas treated with butoxy ethanol or emulsifiable acid formulations of 2,4,5-T applied by mist blower. Streams in Pennsylvania and New Jersey were sampled, and in each case, about 0.04 ppm herbicide was detected immediately after application. Residue levels declined about 50 percent in 4 hours, and no residues were detected in samples collected at various intervals over the next 4 weeks. Samples were collected in connection with the first storm to produce more than 1 in. precipitation. The two Pennsylvania streams contained 0.01 and 0.02 ppm 2,4,5-T after the storm, but the New Jersey streams contained no detectable herbicide. This study is limited by the nonspecific detection method.

Pierce (1969) applied 2,4,5-T (and other herbicides) to prevent revegetation on an experimental watershed in New Hampshire. Samples were collected for more than 1.5 years, and the concentration of 2,4,5-T did not exceed 0.001 ppm.

These various studies largely support the conclusion that direct application and drift are the principal sources of phenoxy herbicides in streams. Direct application and drift to surface waters can largely be controlled through careful orientation of spray units to streams and by careful attention to climatic, equipment, and application factors. Buffer strips more than 100 feet in width do not appear to be necessary.

Survey Monitoring

Brown and Nishioka (1967) reported no 2,4-D, 2,4,5-T, or silvex were found in water-suspended sediment mixtures from 11 streams (major rivers) in the western United States in 1965 and 1966. However, insecticides were found at one time or another in small amounts which included aldrin, DDD, DDE, DDT, dieldrin, endrin, heptachlor, heptachlorelpoxide and lindane. Samples were taken monthly.

Data from the U.S. Geological Survey program for monitoring pesticides in streams of the western United States from October 1966 to September 1968 indicated detection of 2,4-D, 2,4,5-T and silvex in small amounts in some rivers (Manigold and Shulze 1969). The highest concentration of herbicide found was 0.00035 ppm of 2,4-D in the James River at Huron, South Dakota in July 1968. The established water quality criteria at that time permitted 0.1 ppm for herbicides. 2,4-D, 2,4,5-T, and silvex occurred 14, 8, and 3 times at the 20 stations of 19 rivers sampled, respectively. Samples were taken monthly with 2,4-D appearing most frequently in spring months in the Arkansas, Huron, and Yakima Rivers in Arkansas, South Dakota, and Washington, respectively. The occurrence of 2,4,5-T was greatest in the Arkansas and Canadian Rivers in Arkansas and Oklahoma. Silvex was found most frequently in the Humboldt River near Rye Patch, Nevada.

Monitoring studies from 20 stations on 19 western streams for pesticides from 1968 to 1971 detected 2,4-D, 2,4,5-T, and silvex in small amounts (Schulze et al. 1973). During this period, 2,4,5-T was the most common herbicide found (109 occurrences), although the number of occurrences of 2,4-D found (103) was similar to 2,4,5-T. The highest concentration of an herbicide was 2,4-D at 0.0097 ppm. Concentrations were highest in water samples containing appreciable amounts of suspended sediments. Greatest occurrence of 2,4-D was in the Huron and Yakima Rivers; 2,4,5-T in Arkansas and Canadian Rivers; and silvex in the Humboldt River in Nevada.

An analysis of 2,4-D, 2,4,5-T, and silvex in streams in Nebraska indicated small amounts of these herbicides were detected with a maximum concentration 0.00053, 0.001, and 0.00008 ppm for 2,4-D, 2,4,5-T, and silvex, respectively (Petri 1972).

An extensive analysis of surface water of Texas in 1970 for 2,4-D, 2,4,5-T, and silvex revealed only trace levels or less of these herbicides (Dupuy and Schulze 1972). Usually less than 1 million acres of brush are sprayed with 2,4,5-T annually. About 2 million acres of pasture weeds are sprayed annually with 2,4-D in Texas out of a total of 106 million acres of range and pasturelands (Hoffman 1975a). Obviously substantial quantities of herbicide are introduced into the Texas environment each year. The lack of significant herbicide residues from these applications is clear evidence of a combination of careful application and favorable environmental conditions that largely restrict herbicide residues to the treated areas.

Impounded Water

Silvex is cited extensively in this section because 2,4,5-T is normally not applied to impounded water sources. The physical, chemical, and biological properties of 2,4,5-T and silvex are quite similar. The propylene glycol butyl ether ester of silvex, a herbicide useful to control aquatic weeds, hydrolyzed almost totally to the acid of silvex in about 2 weeks when applied at 8 lb/A to water overlying Cecil sandy clay loam, Lakeland loamy fine sand, and Brighton soil in plastic pools (Cochrane et al. 1967). Silvex acid increased in concentration in water for a week and then dissipated gradually over a 19-week period. Apparent adsorption of both the ester and acid occurred on the hydrosoil and was followed by gradual diminution of both. The possibility exists that silvex acid and/or a degradation product may be desorbed and readmitted to water.

Bailey et al. (1970) studied the degradation kinetics of the propylene glycol butyl ether ester of silvex and its persistence in water and mud under impounded conditions. The silvex was applied to the surface of three ponds at 8 lb/A. The hydrolysis of the PGBE ester of silvex to silvex obeyed the first order reaction kinetics, the specific reaction rate constants for the three ponds being 0.09 hr^{-1}, 0.10 hr^{-1} and 0.14 hr^{-1}. About 50 percent hydrolysis of the ester occurred in 5 to 8 hours, 90 percent in 16 to 24 hours and 99 percent in 33 to 49 hours. The concentration of silvex in water initially increased, but decreased to zero in three weeks. Adsorption of both the ester of silvex and silvex appeared to occur on the sediment with complete disappearance of both by the fifth week following treatment.

Groundwater

Residues of phenoxy herbicides tend to remain in upper soil layers. The possiblity of 2,4,5-T getting into groundwater supplies in significant amounts is remote even with repeated or high rates of treatment. The interception of these herbicides by vegetation and litter after application and their rapid breakdown and dilution in plants and soils limits their leachability to the lower soil profile.

Linden et al. (1963) studied the possible threat to groundwater using diesel oil (a common carrier for 2,4,5-T sprays) at 53 to 535 gallons per acre. At 53 gal/A the oil did not penetrate the upper layer of soil from 0 to 4 in. At 267 gal/A of diesel oil (with litter removed), 1.5 to 2 ppm oil occurred in the upper 4 in. of soil with traces to 8 in. At 535 gal/A of diesel oil, the upper 4 in. contained 9 ppm oil and the 8 in. depth contained 1 ppm. With the humus layer intact, 1.5 to 2 ppm oil was found in the upper 4 in. layer of a sandy loam soil with only traces of oil within the 8 in. layer. The investigators conclude the use of 53 gallons per acre of diesel oil on forest soil in no way endangers the water table. The use of more than 53 gal/A of diesel oil as an herbicide carrier for 2,4,5-T, silvex or 2,4-D plus 2,4,5-T, even for control of individual woody plants, would be uncommon.

O'Connor and Wierenga (1973) studied the degradation and movement of extremely high rates of 2,4,5-T (57 lb/A) in lysimeter columns in the greenhouse. They concluded that pollution of groundwater from normal application rates of less than 2 lb/A of 2,4,5-T is unlikely because of its relatively slow rate of movement in soil and rapid biological detoxification.

Edwards and Glass (1971) applied 10 lb/A of 2,4,5-T acid to a large field lysimeter in Ohio. The total amount of 2,4,5-T found in percolation water intercepted 2.5 meters deep up to 1 year after application, was considered insignificant.

Bovey and Baur (1972) found no 2,4,5-T or very small amounts at lower soil depths at five widely separated locations in Texas after treatment with the propylene glycol butyl ether esters of 2,4,5-T at 0.5 and 1 lb/A.

Bovey et al. (1975) conducted an investigation to determine the concentration of 2,4,5-T and picloram in subsurface water after spray applications of the herbicides to the surface of a seepy area watershed and lysimeter in the Blacklands of Texas. A 1:1 mixture of the triethylamine salts of 2,4,5-T plus picloram was sprayed at 2.24 2 lb/A every 6 months on the same area for a total of five applications. Seepage water was collected at 36 different dates and 1 to 6 wells were sampled at 10 different dates during 1971, 1972, and 1973. Concentration of 2,4,5-T and picloram in seepage and well water from the treated area was extremely low (<1 ppb) during the 3-year study. No 2,4,5-T was detected from 122 drainage samples from a field lysimeter sampled for 1 year after treatment with 1 lb/A of a 1:1 mixture of the trithylamine salt of 2,4,5-T plus picloram. Picloram was detected in small amounts (1 to 4 ppb) 2 to 9 months after treatment in lysimeter water. Supplemental irrigation in addition to a total of 34 in. of natural rainfall was used to attempt to force 2,4,5-T and picloram into the subsoil.

Processes of 2,4,5-T Disappearance in Water

Phenoxy herbicides are not persistent in water, and significant concentrations, if found, occur for a relatively short time after treatment. Loss of herbicides from treated areas by movement in runoff water is usually a very small percentage of the total amount applied even under intensive natural or simulated rainfall conditions. The phenoxy herbicides rapidly dissipate in streams and are difficult to detect some distance downstream from the point of application. In impounded water they decompose rapidly, especially if adapted microorganisms are present. Insignificant amounts of phenoxy herbicides appear in ground or subsuface water due to their rapid breakdown and their slow movement into the soil profile. In surveys of major river systems in the U.S., 2,4-D and especially silvex and 2,4,5-T appear infrequently in very minute concentrations, well below levels believed to be biologically active.

In addition to the usual degradation processes in water, herbicide residue levels decrease in surface runoff water or flowing water by simple dilution. This is best illustrated in research work or commercial operations where ditch banks are treated for weed control and subsequent water samples are taken at the point of application and at several points downstream. A point downstream is soon reached (depending upon the volume and rate of flow) where the herbicide cannot be detected.

Photodegradation of 2,4-D and 2,4,5-T by ultraviolet light may be significant in the natural environment (Crosby and Wong 1973, Aly and Faust 1964). The rate of 2,4-D photodegradation is increased as the pH of the solutions increase. Fortunately the phenol produced as an intermediate in the degradation of 2,4-D is destroyed by light even more rapidly. It is reasonable to assume that other 2,4,5-T phenoxy compounds undergo similar degradation.

2,4,5-T may be applied to water in rice fields or fields may be flooded soon after herbicide application. Although the pH and temperature of the floodwater that initially enter the ricefield may vary, they reach equilibrium soon after application. The pH of the floodwater at midseason when 2,4,5-T is applied for weed control ranges from 7.3 to 9.0 (Gilmore 1978). The floodwater temperature at midseason (July) when 2,4,5-T is applied for weed control, ranges from 85 to 92°F for maximums or from 74 to 77°F for minimums (Downey and Wells 1975). These conditions favor rapid ester hydrolysis and biological degradation of herbicide residues.

AIR - RESIDUES AND FATE

Sources of phenoxy herbicides in air are from spraying or volatilization from soil, plant, or water surfaces after spraying. Type of spray equipment, weather conditions and herbicide formulation, and carriers all influence loss of herbicides into the air. Control of spray drift is especially important with ground or aerial equipment since phenoxy herbicides may affect valuable vegetation near treated areas.

Initial concentrations in air from spraying or volatilization was discussed earlier. Small spray droplets may drift long distances and affect off-site vegetation. However, the amount of 2,4,5-T or similar herbicide which moves via spray drift or volatilization to nearby nontarget areas is extremely small (but sensitive plants may show characteristic symptoms of exposure).

Grover et al. (1972) studied the relative drift of droplet and vapor of butyl ester and dimethylamine formulations of 2,4-D under field conditions using labelled herbicides. The ground deposit and the airborne spray particles drifting from the target area were collected. The mass of dimethylamine and butyl ester of 2,4-D drifting as droplets was 3 to 4 percent of the material sprayed. No significant amounts of the amine were collected as vapor or particulate drift. However, 20 to 30 percent of the butyl ester of 2,4-D was collected as vapor drift up to one-half hour after spraying. Thus, the drift potential of the butyl ester was about 8 to 10 times greater than the amine formulation in these studies. A similar pattern probably occurs for 2,4,5-T.

Flint et al. (1968) investigated the volatility and vapor pressure of the four most common commercial low-volatile esters compared to a high-volatile ester using gas-liquid chromatography. The order of increasing volatility and the vapor pressure of these esters in mm of Hg at 187°C are as follows: isooctyl - 2.7; 2-ethylhexyl - 3.0; butoxy ethanol - 3.9; propylene glycol butyl ether - 3.9; compared to the reference, isopropyl - 16.7. Similar data have been reported by Grover (1976). Since the butyl ester used in studies by Grover et al. (1972) is considered a high-volatile ester, one would expect reduced vaporization loss from treated areas with low-volatile esters of 2,4-D and 2,4,5-T, as reported by Flint et al. (1968) and Grover (1976).

Monitoring Data

Monitoring data during the spraying season in Canada and the Northwest indicate that the concentration of ester of 2,4-D in the atmosphere varies from 0 to 10 $\mu g/m^3$ or about 0 to 1 ppb (Adams et al. 1974, Hay and Grover 1967). The relative increasing order of volatility of the various esters of 2,4-D is isopropyl, butyl, and isooctyl. At two sampling locations in Washington, the isopropyl ester was found the greatest numbers of days sampled and in highest average concentration in air, followed by the butyl ester of 2,4-D (Adams et al. 1974). Although the isooctylester was found infrequently and in low amounts (0.001 to 0.007 $\mu g/m^2$) on the average in one case, it was found at a maximum concentration of 3.1 $\mu g/m^3$. The researchers were somewhat surprised to find the isopropyl ester since its use was banned in Oregon and parts of Washington.

In other studies, Bamesberger and Adams (1966) collected 24-hour fractions of airborne aerosol and gaseous herbicides at Pullman and Kennewick, Washington field sites for approximately 100 days. The isopropyl ester of 2,4-D was detected most frequently (about 1 out of 3 days) at both sites. Other formulations of 2,4-D were methyl, butyl, and isooctyl. At Pullman, most phenoxy herbicides collected were as larger aerosol droplets, whereas in the hotter, dryer climate at Kennewick, smaller aerosol droplets and gases were most frequent. Herbicides not detected included MCPA, the 2-ethylhexyl ester of 2,4-D, 2-ethylhexyl ester of 2,4,5-T, and the isooctyl ester of 2,4,5-T. The methyl ester of 2,4,5-T was found infrequently (9 out of 99 and 14 out of 102 days) at Pullman and Kennewick, Washington, respectively. Maximum concentrations of phenoxys were the methyl esters of 2,4,5-T and 2,4-D at 3.38 and 5.12 $\mu g/m^3$, respectively.

Cohen and Pinkerton (1966) established that pesticides can be transported from a point remote from their application by winds picking up treated soil, transporting it over short or long distances and depositing it by simple sedimentation or by rain. DDT and other insecticides have been found in rainfall; 2,4,5-T has been found in dust.

Processes of 2,4,5-T Disappearance in Air

The fate of the phenoxy herbicides in air has received limited investigation. Certainly the tremendous space of the atmosphere may quickly dilute and disperse smoke, dust, and other small particles by virtue of air movement. Small amounts of pesticides likewise are quickly diluted to insignificant levels. However, if proper application techniques are not followed, spray drift or vapor may result in sufficient levels of phenoxys to affect nearby vegetation.

Photodegradation of phenoxy herbicides in air probably also accounts for its rapid loss. Destruction of other herbicides in vapor form are known to occur from natural sunlight (Ketchersid et al. 1969).

If attached to dust and other particles, the chemical may eventually settle to the soil surface or occur in rainfall remote from the point of application. Amounts occurring from air movement over long distances are insignificant relative to toxic and phytotoxic effects and accumulation in the food chain.

ANIMALS - RESIDUES AND FATE

Livestock

Early work with 2,4-D, 2,4-DB, MCPA, and MCPB indicated these herbicides did not produce detrimental effects in cattle-grazing treated pastures and that the bulk of the herbicides was eliminated in the urine the first day or two after feeding.

St. John et al. (1964) fed Holstein cows 5 ppm of atrazine, silvex, or 2,4,5-T in daily rations for four days. No residues of these herbicides were found in milk. Silvex (acid) and 2,4,5-T appeared to be totally eliminated in the urine as salts within 5 or 6 days after feeding was started. About 67 percent of the propylene gylcol butyl ether ester of silvex was hydrolyzed to the sodium salt and eliminated in urine.

In actual field grazing trials, Klingman et al. (1966) found from 0.01 to 0.09 ppm of 2,4-D in milk during the first two days after spraying, and lower amounts thereafter. Low-volatile and high-volatile esters of 2,4-D were sprayed on separate pastures at about double the usual rates (2 lb/A). If cows were put into pastures four days after spraying, no residues of 2,4-D were found. The practical lower limit of precision of the method used was 0.01 ppm.

Bjerke et al. (1972) reported residues of phenoxy herbicides in milk and cream after feeding high levels (10 to 1,000 ppm) for prolonged periods of time (2 to 3 weeks). The average residues found in milk at the highest feeding level (1,000 ppm) and the corresponding phenol are in table 6.

Lower limit of sensitivity of the method was 0.05 ppm. Concentrations of phenoxy herbicides were low considering the high levels fed. No residues of 2,4,5-T, 2,4-D, or MCPA, or their corresponding phenol greater than 0.05 ppm were found in milk and cream up to 30, 300, and 1,000 ppm feeding levels, respectively. Residues of silvex were found only at the 1,000 ppm feeding level. No significant difference was found between residues in milk and cream. Residues of all chemicals decreased rapidly upon removal of the chemicals from the feed.

Research by Clark et al. (1975) feeding 2,4-D, 2,4,5-T, and silvex to sheep and cattle confirms earlier work by these and other investigators.

Table 6—Residues of phenoxy herbicides and corresponding phenol in milk after exposing cows to 1000 ppm in their feed for 3 weeks (Bjerke et al. 1972)

Chemical	PPM
2,4-D	0.06
2,4-dichlorophenol	0.05
2,4,5-T	0.42
2,4,5-trichlorophenol	0.23
silvex	0.12
2,4,5-trichlorophenol	0.05
MCPA	0.05
2-methyl-4-chlorophenol	0.06

Residues of 2,4-D, 2,4,5-T, and silvex, and their phenol metabolites fed at 0, 300, 1,000, and 2,000 ppm for 28 days were determined in muscle, fat, liver, and kidney. Muscle and fat contained the least residue; kidneys contained the highest. Liver and kidney contained the highest levels of either 2,4-dichlorophenol or 2,4,5-trichlorophenol. No species difference in regard to 2,4-D, 2,4,5-T, and silvex residue deposition was observed. The doses of herbicides used in this and many other studies represent an exposure in excess of that expected on forage or hay under normal conditions. The higher levels (1,000 and 2,000 ppm) are several-fold greater than encountered in agricultural practices. The investigators conclude that residues of phenoxy herbicide or phenolic metabolites in meat of sheep or cattle are unlikely under proper agricultural uses. It is interesting that no adverse effects, other than decreased weight gain due to anorexia, were observed for any of the herbicides at any level of ingestion. Data for the high feeding level for cattle are given in table 7.

Considering the high level of herbicide fed, the residues are remarkably low. Lower feeding rates resulted in lower tissue residues. Withdrawal from treatment for 1 week before killing resulted in significant reduction in tissue residue levels. These data provide sound evidence that these herbicides or their phenolic metabolites do not accumulate in animal tissue.

Small Animals

The fate of 2,4,5-T in animals exposed in the field may proceed as in controlled experiments discussed below. Female C57BL/6 mice received a single 100 mg/kg subcutaneous injection of 2,4-D and 2,4,5-T acids and the butyl and isooctyl esters of 2,4-D (Zielinski and Fishbein 1967). The esters of 2,4-D disappeared more rapidly than the free acids. No 2,4-dichlorophenol was detected in animals treated with 2,4-D acid or its butyl or isooctyl esters. Pretreatment with the same herbicide enhanced the disappearance rate only for the 2,4-D butyl ester. A relatively prolonged body residence time was observed for 2,4,5-T (<24 hours).

Table 7--Residues of phenoxy herbicides and their phenolic metabolites in cattle fed 2,000 ppm of each for 28 days[a]

	Residues found			
	Muscle	Fat	Liver	Kidney
	ppm			
2,4-D	0.07	0.34	0.23	10.9
2,4-D phenol	0.05	0.05	0.31	1.06
2,4,5-T	1.00	0.27	2.29	27.2
2,4,5-T phenol	0.13	0.05	6.1	0.90
2,4,5-T[b]	0.05	0.05	0.05	0.06
2,4,5-T phenol[b]	0.05	0.05	4.4	0.81
Silvex	0.70	3.77	8.37	23.6
2,4,5-T phenol	0.05	0.05	0.42	0.10
Silvex[b]	0.12	0.67	0.55	1.13
2,4,5-T phenol[b]	0.05	0.05	0.13	0.06

a/ Clark et al. 1975.

b/ Seven days after herbicide removed from feed.

Lindquist and Ullberg (1971) found that after injection of 2,4,5-T-C^{14} to pregnant mice (0.09 mg 2,4,5-T) the radioactive substance did not, to any appreciable extent, reach the embryo. The only organs with higher concentrations than the blood were the kidneys and the visceral yolk sac epithelium. As early as 5 minutes after injection, the concentration in the yolk sac epithelium exceeded that in the blood. Concentration in the brain was low. There was no site of accumulation in the fetal tissues. Labelled 2,4-D accumulated slightly in the visceral yolk sac, passed to the fetus and was rapidly eliminated from all tissues, including the visceral yolk sac (within 24 hours).

Several investigators have studied the fate of 2,4,5-T in rats and dogs (Courtney 1970, Fang et al. 1972 Grunow and Boehme 1974, Hook et al. 1974, Piper et al. 1973a). The 2,4,5-T is widely distributed in all tissues a few hours after treatment, but declines rapidly thereafter. A majority of the 2,4,5-T is excreted (similar to 2,4-D) within one to three days after dosing. Grunow and Boehme (1974) reported conjugates with glycine and taurine, as well as 2,4,5-trichlorophenol metabolite. Fang et al. (1972) indicated highest concentrations were found in the kidneys. Courtney (1970) reported placental and fetal levels of 2,4,5-T were proportional to maternal serum levels but that rat liver homogenates did not metabolize 2,4,5-T. Piper et al. (1973b) showed that the distribution, metabolism, and excretion of 2,4,5-T were markedly altered when large doses are administered in rats. For example, the half-life for clearance of ^{14}C activity from plasma of rats given 5, 10, 100, or 200 mg/kg were 4.7, 4.2, 19.4, and 25.2 hours, respectively; half-lives for elimination from the body were 13.6, 13.1, 19.3, and 28.9 hours, respectively. In dogs, the half-life values were much longer than for rats and appreciable excretion in feces was noted. In urine, three unidentified metabolites were detected, indicating a different metabolism of 2,4,5-T by dogs than rats and may explain why 2,4,5-T is more toxic to dogs than rats.

Wildlife

In actual field studies, Newton and Norris (1968) found that blacktail deer did not accumulate large amounts of 2,4,5-T from browzing in areas that had been treated with 2 lb/A of the herbicide in the Oregon Coast Ranges. Concentrations in flesh rarely reached detectable levels and the ruminant was able to degrade and eliminate the herbicide soon after ingestion.

Erne (1974) found acute and chronic toxicity of 2,4-D and 2,4,5-T in reindeer to be comparable to those observed in laboratory and domestic animals. Residues of phenoxy herbicides were found only occasionally in wildlife and at low concentration. Feeding of phenoxy herbicide-treated vegetation to rabbits and pregnant reindeer for a few months did not affect health or fetal development in offspring.

Honey bee (*Apis mellifera* L.) colonies were fed 2,4,5-T in water at 1,000 ppm (Morton et al. 1974). Concentrations of 2,4,5-T in honey bees from this excessively high rate was 148 ppm but declined to about 5 ppm as soon as the bees began using untreated water. Brood production was reduced during 2,4,5-T feeding, but returned to normal 3 months after 2,4,5-T feeding ceased.

Humans

Although large amounts of 2,4-D, 2,4,5-T, and the related compounds have been manufactured and used. Clinical reports of poisoning are rare. Nielsen et al. (1965) reported a case of suicide with ingestion of the diethylamine salt of 2,4-D. He observed 6.0 g of 2,4-D in the corpse of the victim, corresponding to a lethal dose of 80 mg/kg or more. Seabury (1963) reported another case in which he administered 3.6 g of sodium salt of 2,4-D through intravenous infusion to a patient suffering from disseminated coccidioidomycosis. The patient was troubled with twitchings of the muscles and fell into stupor, but recovered.

Matsumura (1970) determined orally administered 2,4,5-T to man was excreted in the urine as in experimental animals. Volunteers took 100 or 150 mg of 2,4,5-T orally. The 2,4,5-T was readily absorbed and eliminated gradually from the blood plasma, showing a first-order elimination rate. More than 80 percent of the orally administered 2,4,5-T was excreted in the urine unchanged within 72 hours. Little 2,4,5-T was found in urine of workers in a 2,4,5-T factory; however, concentrations in air in the working areas were also less than the recommended maximum concentration (10 ng/mg^3). Other researchers (Gehring et al. 1973, Kohli et al. 1974) reported similar findings to Matsumura (1970). Gehring et al. (1973) found essentially all the orally ingested 2,4,5-T was absorbed into the body and excreted unchanged in the urine.

PART 3: BEHAVIOR AND FATE OF TCDD IN THE ENVIRONMENT

This topic is treated separately from 2,4,5-T because the literature base is smaller and because risk assessment (including exposure analysis) is handled separately in PD-1.

VEGETATION - RESIDUES AND FATE

Crosby and Wong (1977) analyzed the persistence of TCDD in actual herbicide formulations on leaves, soil, or glass plates. When exposed to natural sunlight, most of the TCDD was lost in less than 6 hours from leaves. This loss was due principally to "photochemical declorination." The herbicide formulation provides a hydrogen donor which allows rapid photolysis to occur. Pure TCDD, as used in earlier experiments, would not have been subject to photolysis because a hydrogen donor was lacking. Despite the known persistence of pure TCDD, it is not stable in thin films of formulated herbicide when exposed to outdoor light. Studies are currently in progress at the USDA Forest Service Pacific Northwest Forest and Range Experiment Station to quantify TCDD loss from vegetation and soil under various levels and qualities of light in the forest. They should be completed by October 15, 1979.

Plant uptake of TCDD from soils does not appear to be significant. Soybean and oat plants took up only trace amounts of TCDD in the first 10 to 14 days after exposure to sandy soil containing 200,000 times the amount of TCDD contained in an application rate of 2 pounds per acre 2,4,5-T (with 0.1 ppm TCDD). No detectable TCDD was in the grain or beans at maturity, probably due to normal dilution by plant growth, volatilization, or photodecomposition on the leaf surface, and metabolism. TCDD is not translocated from the point of application on the leaf surface to other parts of the plant and some is washed off with rain water (Isensee and Jones 1975).

SOIL - RESIDUES AND FATE

Earlier laboratory experiments (Kearney et al. 1972) indicated that pure TCDD on soil surfaces was not degraded by sunlight. Crosby and Wong (1977) have demonstrated that TCDD, as it actually occurs in formulated herbicide products, is rapidly degraded (about 15% in six hours) on the soil surface by the action of sunlight. In five soils with widely varying properties, TCDD was found to be immobile even when subjected to leaching (Helling et al. 1973). The possiblity of TCDD entering groundwater is remote (Tschirley 1971). If TCDD is incorporated into soil, it disappears slowly. About half the TCDD is lost after one year (Kearney et al. 1972). It seems unlikely, however, that TCDD would be incorporated in soils under most conditions of use, since it does not leach into the soil. TCDD is not produced from breakdown products of 2,4,5-T in soils or in sunlight (Kearney et al. 1973).

WATER - RESIDUES AND FATE

TCDD is nearly insoluble in water - 0.2 ppb. For this reason, it would be expected to remain on the surface of plants and soil at the application site. Because it is immobile in soils, Kearney et al. (1973) concluded there would be "no ground water contamination problem." In the natural environment, TCDD would be associated with other less water soluble constituents of formulation. They would form a thin film on water surfaces. Such films are expected to be degraded by sunlight, much like the thin films on vegetation or the soil surface studied by Crosby and Wong (1977). Residues might, therefore, be substantially less than would be expected based on research in laboratory systems which suggests that TCDD would be only slowly degraded in water.

The actual levels of TCDD in vegetation, forest floor, soil, and water have not been measured. They can be estimated however, from initial residue levels of 2,4,5-T (Norris et al. 1977) (assuming 2,4,5-T contains 0.1 ppm TCDD) and the TCDD persistence characteristics reported by Crosby and Wong (1977), Kearney et al. (1973) and Miller et al. (1973) apply (table 8). Verification of these values is needed from actual residue studies.

ANIMALS - BIOACCUMULATION

Bioaccumulation means the uptake and at least temporary storage of a chemical by an organism. TCDD is present in such minute quantities in the environment that primary exposure [that is, exposure resulting from direct ingestion (of vegetation or water) dermal absorption, or inhalation] is limited (Norris et al. 1977). Bioaccumulation is a mechanism by which organisms may collect or concentrate TCDD from primary exposure. If significant bioaccumulation occurs these organisms (as food sources for other creatures) could possibly carry toxicologically significant residues. The question is, then, does bioaccumulation occur, and if it does, to what degree? There are three ways to study this question: physical-chemical properties, laboratory studies, and environmental monitoring.

PHYSICAL-CHEMICAL PROPERTIES

Physical-chemical properties are good indicators of the potential for bioaccumulation. Chemicals with low water solubility and high fat solubility have a strong potential for bioaccumulation. DDT is an example of a chemical which is low in water solubility (0.001 ppm), high in fat solubility (86,000 ppm in corn oil) and is known to bioaccumulate in exposed organisms. TCDD is low in water solubility (0.0002 ppm) but is also low in fat solubility (47 ppm in corn oil). The ratio of oil solubility to water solubility is 86×10^6 for DDT and 0.2×10^6 for TCDD. These physical-chemical properties suggest that TCDD would bioaccumulate in exposed organisms, but probably to a lesser degree than DDT. The degree of bioaccumulation depends on the magnitude and duration of organism exposure.

Table 8--Calculated residues of TCDD in the forest after aerial application of 2,4,5-T (containing 0.1 ppm TCDD) at 2 lb/A[a]

Time after application	Vegetation	Forest floor	Soil	Water
(weeks)	ng/kg[b]	ng/m^2	ng/kg[b]	ng/liter[b]
0	5	4	0.001	1
1	0.001[c]	0.5[c]	0.001[d]	$1x10^{-6}$[e]
4	—	0.004	0.0009	—
16	--	--	0.0008	—
26	—	—	0.0006	—
52	—	—	0.0005	—

a/ Calculated from Norris et al (1977).

b/ Part per trillion.

c/ Assumes TCDD persistence reported by Crosby and Wong (1977).

d/ Assumes TCDD persistence reported by Kearney et al. (1973).

e/ Assumes TCDD persistence reported by Miller et al. (1973).

LABORATORY STUDIES

Bioaccumulation can also be studied in laboratory animals or in small laboratory ecosystems. Several such studies have been done. Data from laboratory feeding studies of mammals and fish and from laboratory-scale aquatic ecosystems are pertinent.

In laboratory feeding studies involving repeated exposure, Fries and Marrow (1975) report that after six weeks of exposure, rats reached a steady state which was 10.5 times the daily intake. Rose et al. (1976) also report steady state concentration in rates in seven weeks at a little more then ten times the daily intake level. These data establish that in laboratory feeding studies, animals which ingest TCDD in their diet will accumulate TCDD in certain body tissues, at least for as long as exposure continues.

It is also clear, however, that TCDD is not irreversibly accumulated in these feeding studies. Piper et al. (1973), Allen et al. (1975) Rose et al. (1976), and Fries and Marrow (1975) all found a halflife for TCDD residence in the body which ranged from approximately 12 to 30 days. These data indicate that once exposure to TCDD stops, the body burden will decrease. In a feeding study with rainbow trout, Hawkes and Norris (1977) reported limited and preliminary data indicating that on a whole body basis, TCDD levels in fish are approximately of the same order of magnitude as the level of TCDD in the food which they consume.

Several laboratory-scale aquatic ecosystem studies have been conducted with TCDD. Matsumura and Benezet (1973) exposed several organisms to TCDD in model aquatic ecosystems. Unfortunately, in most of their studies the concentration of TCDD in the water was substantially in excess of the limits of its solubility, preventing meaningful interpretation of the data. In one experiment, however, TCDD was adsorbed on sand in the bottom of the aquariums and Matsamura and Benezet found 0.1 ppb TCDD in water and 157 ppb in brine shrimp, to give a concentration factor of 1,570.