WEEDS AND THEIR CONTROL in RICE PRODUCTION

Agriculture Handbook No. 292

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
in cooperation with
Arkansas Agricultural Experiment Station

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By
Roy J. Smith, Jr., and W. C. Shaw
Crops Research Division
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PRECAUTIONS

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Keep pesticides in closed, well-labeled containers in a dry place. Store them where they will not contaminate food or feed, and where children and animals cannot reach them.

When handling a pesticide, wear clean, dry clothing.

Avoid repeated or prolonged contact of pesticide with your skin.

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PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

Mention in this handbook of commercially manufactured equipment or the use of trade names of products does not imply endorsement by the U.S. Department of Agriculture over similar equipment or products not mentioned.

Contents

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WEEDS AND THEIR CONTROL IN RICE PRODUCTION

By ROY J. SMITH, JR., and W. C. SHAW, *Crops Research Division, Agricultural Research Service*

INTRODUCTION

Weed control is one of the most laborious and expensive steps in rice production. In underdeveloped countries, such as India, Indonesia, Korea, and Pakistan, weeds are removed by hand weeding. In developed countries, such as Australia, France, Italy, Japan and the United States, weeds are removed primarily by chemical-cultural weed control methods.

In 1962 herbicides were used to control weeds on 940 thousand acres of riceland in the United States—about 52 percent of the rice acreage—at a cost of more than $6 million (*80*).[1] Weeds are a problem on almost every acre of rice grown in the United States. As new herbicides are developed for controlling weeds in rice, herbicides will be used more extensively. The development, acceptance, and use of cultural, chemical, and combination methods of weed control in rice have been outstanding.

Cultural methods of controlling weeds in rice are an integral part of rice production. These methods include seeding weed-free crop seed, practicing crop rotations, leveling land, thoroughly preparing seedbeds before seeding the crop, selecting seeding methods that reduce weed problems, and managing water and fertilizer properly. Where cultural methods do not control weeds effectively, herbicides can be used advantageously. However, combinations of cultural and chemical practices are more effective in controlling weeds in rice than either practice used alone. The interdependence and the interrelations of cultural and chemical methods of weed control in rice production are emphasized in this handbook.

This handbook is designed as a guide on weed control in rice for research scientists, extension specialists, county agents, vocational agriculture teachers, and organizations concerned with rice production research and education in the United States and abroad.

Since the status of chemical weed control in rice is changing rapidly, and new herbicides or new uses for older ones are being recommended, it is important to keep in touch with the U.S. Department of Agriculture, State agricultural experiment stations, or manufacturers of specific products for up-to-date information.

THE WEED PROBLEM

Conditions favorable for growing rice are also favorable for the growth and reproduction of terrestrial, aquatic, and semiaquatic weeds. Weeds in rice produce an abundance of viable seeds, and once these seeds infest the soil they are difficult to remove. The practice of seeding rice by broadcasting or drilling prevents cultivation after emergence to remove weeds. The best approach to weed control in rice is to prevent weed infestations by seeding weed-free rice and removing scattered weed seedlings from the field before they produce seed. After the soil becomes infested with weeds, however, they may be effectively controlled by a combination of selected cultural and chemical methods.

[1] Italic numbers in parentheses refer to literature included in Bibliography, p. 61.

Effect of Weed Competition on Growth of Rice

Weeds compete with rice for light, nutrients, water, and other growth requirements. They reduce yields, lower the market value of the crop by reducing quality, and increase the cost of harvesting, drying, and cleaning.

Both research and grower experience indicate that weeds reduce the average yield of rice in the United States about 13 percent. Weeds also cause losses of about 4 percent in the quality of the harvested crop and losses of about 3 percent due to extra land preparation, water, and fertilizer. Thus, losses in the rice crop due to weed competition amount to about 20 percent of the potential farm value of the rice crop, or more than $60 million each year. In addition, farmers spend about 9 percent of the value of the rice crop to control weeds by cultural, mechanical, and chemical methods, or almost $24 million each year. Therefore, annual losses caused by weeds in the rice crop in the United States and the cost of their control amount to approximately $84 million.

Barnyardgrass [2] is a serious problem in all ricegrowing areas of the United States. In one field investigation at Stuttgart, Ark., plots with one barnyardgrass plant per square foot and with an optimum stand of rice yielded 4,380 pounds per acre of rough rice compared with 5,350 pounds from grass-free plots. Plots with five barnyardgrass plants per square foot yielded 3,440 pounds per acre. Thus, barnyardgrass at stands of one and five plants per square foot reduced rice yields 18 and 36 percent, respectively.

In another field experiment at Stuttgart, Ark., barnyardgrass was allowed to compete with rice for 9 days after its emergence, then was removed by handweeding and kept out thereafter. The grass was removed when it had one to three leaves. Plots of rough rice yielded 4,610 pounds per acre. When barnyardgrass competed with rice for 16 and 23 days (an additional 1 or 2 weeks), plots yielded only 3,830 and 3,810 pounds, respectively—a 17-percent reduction as compared with competition for 9 days.

Extensive cooperative investigations by the chemical industry and ricegrowers showed that in Arkansas weeds reduced rice yields approximately 74 percent; in Louisiana, 35 percent; in Mississippi, 64 percent; in Texas, 48 percent; and in California, 36 percent (*15*). The most destructive weed in these investigations was barnyardgrass, although other grass weeds, sedges, broadleaf weeds, and aquatic species caused some losses.

[2] Scientific names of weeds are given in the section on weeds, p. 36.

In a 5-year field investigation at Stuttgart, Ark., losses were greater when ducksalad, a destructive aquatic weed, competed with rice for an 8-week period than when it competed for 2 or 4 weeks or all season (table 1). The value of these losses from weed competition ranged from $13 to $72 per acre.

TABLE 1.—*Effect of ducksalad competition on rice, Stuttgart, Ark., 1957-61*

Time of competition after emergence	Rough rice, per acre			
	Yield	Loss in yield		Loss in value[1]
	Pounds	*Pounds*	*Percent*	*Dollars*
0 (check)	5,220			
2 weeks	4,960	260	5	13
4 weeks	4,460	760	14	38
8 weeks	3,780	1,440	28	72
All season	4,100	1,120	21	56

[1] Rough rice valued at $5 per hundredweight.

Sesbania and curly indigo lower the quality of rice and are noxious weeds in seed rice. In Arkansas no sesbania or curly indigo seeds are allowed in foundation and registered seed, and only one seed in 2 pounds of seed rice is permitted in blue tag certified seed (*7*). The quality and value of milled rice is reduced by the presence of either of these species of weeds.

A 2-year field investigation showed that yields of rice decreased as the time sesbania competed with rice after weed emergence increased (table 2). Another field investigation showed that as the number of sesbania plants per acre increased, yields of rice decreased (table 3).

Weeds, such as sesbania, curly indigo, Mexican-weed, and red rice, reduce the value of rice by lowering the quality of the crop. All are difficult to remove from the rice grain. Red rice, for example, differs from white rice by having a red seedcoat instead of the usual brown one. It belongs to the same species as white rice, but in most markets milled white rice is preferred by consumers. Rough rice containing red grains must be milled closely to remove the red seedcoats. Close milling breaks many white rice kernels. Broken rice has less value than whole milled rice. If the red seedcoat is not removed, however, the milled rice is unattractive and its market value is reduced.

TABLE 2.—*Effect of sesbania competition on rice, Stuttgart, Ark., 1961-62*

Time of competition[1]	Rough rice, per acre			
	Yield	Loss in yield		Loss in value[2]
	Pounds	*Pounds*	*Percent*	*Dollars*
0 (check)	5,710			
4 weeks	5,620	90	2	4.50
8 weeks	5,470	240	4	12.00
12 weeks	5,200	510	9	25.50
15 weeks[3]	4,630	1,080	19	54.00

[1] Sesbania population was one-half plant per square foot.
[2] Rough rice valued at $5 per hundredweight.
[3] Sesbania competed until rice was mature.

TABLE 3.—*Effect of sesbania competition on rice, Stuttgart, Ark., 1960-62*

Sesbania plants per acre (number)[1]	Rough rice, per acre			
	Yield	Loss in yield		Loss in value[2]
	Pounds	*Pounds*	*Percent*	*Dollars*
None (check)	5,520			
5,445	5,060	460	8	23.00
10,890	4,770	750	14	37.50
21,780	4,060	1,460	26	73.00
43,560	3,370	2,150	39	107.50

[1] Sesbania competed until rice was mature.
[2] Rough rice valued at $5 per hundredweight.

Dissemination of Weeds

Weeds are disseminated in ricefields by seeding rice that contains weed seed and by transporting weed seeds in irrigation water, on farm machinery, and by birds and animals.

Many weeds are spread almost entirely by seeding rice containing weed seed. Red rice, sesbania, curly indigo, and Mexican-weed are major weeds disseminated with seed rice. Even cleaned seed rice may contain these weed seeds, because they are difficult to separate from the crop seed with available cleaning equipment.

Many weed seeds are very light and are carried by irrigation water. These include seeds of barnyardgrass, curly indigo, ducksalad, and redstem. When these weeds grow to maturity on canal banks and in ricefields, their seeds drop into the water and are disseminated with moving irrigation water.

Machinery used in rice production—for breaking the land and for harvesting—carries weed seed from field to field. Dissemination of weed seed by machinery may be reduced by cleaning the equipment thoroughly between use on each field. Weeds should be controlled in service areas where equipment is cleaned or stored, to prevent weed seed from being carried by equipment into ricefields. Mowing, burning, oiling, grazing, and soil sterilants control weeds in these areas.

Weed seeds are carried by birds, livestock, and wild animals. Some species of blackbirds feed largely on wild grasses, which include paspalums (*Paspalum* spp.), barnyardgrass, crabgrass (*Digitaria* spp.), brachiaria, and foxtail (*Setaria* spp.). The diet of many species of blackbirds contains as much as 10 percent of barnyardgrass seed. Livestock that graze stubble ricefields scatter weed seed either on their hoofs or hide, or through manure. The practice of livestock grazing pastures infested with weeds contributes to the dissemination of weed seed.

Longevity and Dormancy of Weed Seed

Weed seeds remain viable in the soil for many years. In experiments initiated in 1879 in Michigan, freshly gathered seeds of 20 species of weeds were mixed with sand, placed in pint bottles, and buried 18 inches below the ground surface (*11, 73*). After 40 years' burial, viable seeds were present in 12 species of weeds; after 80 years' burial, viable seeds were present in 3 species of weeds—common eveningprimrose (*Oenothera biennis* L.), curly dock (*Rumex crispus* L.), and moth mullein (*Verbascum blattaria* L.).

Although weed seeds are viable, they may be incapable of germination immediately after maturity, even when conditions are favorable. This characteristic is called dormancy. Seeds of cocklebur (*Xanthium* spp.), wild oat (*Avena fatua* L.), and redroot pigweed (*Amaranthus retroflexus* L.) exhibit dormancy (*73*). Seeds of barnyardgrass may lie dormant in the soil for 10 to 48 months after maturity before they will germinate (*3, 4*). Secondary dormancy may occur after a period in which the seeds can germinate. For example, seeds of barnyardgrass were dormant for 10 months immediately after they matured on the plant. They then went through a period in which they germinated. After submergence for 4 or 5 months, these seeds went through a period of secondary dormancy in which they did not germinate. Environmental factors, such as variations in drying and wetting and changes in temperatures, help to break primary and secondary dormancy of barnyardgrass seeds.

Experiments, therefore, indicate that once weed seeds are present in the soil they infest ricefields for many years.

CULTURAL METHODS OF WEED CONTROL

Cultural practices of weed control are those that (1) prevent or reduce weed infestations, (2) suppress weed growth, and (3) kill weeds. Cultural methods of controlling grass and broadleaf weeds in rice predominate in the United States. Weed-free seed, crop rotations, land leveling and levee construction, seedbed preparation, seeding methods, and water and fertilizer management are all vital in a weed-control program. The use of herbicides in combination with effective cultural practices is more effective in controlling weeds in rice than either cultural or chemical methods used alone.

Weed-Free Seed

Planting weed-infested crop seed is one of the major ways of infesting clean fields with weeds. Red rice, a serious weed in ricefields, is spread largely by planting rice seed containing seeds of red rice. Other weeds, such as sesbania, curly indigo, barnyardgrass, Mexican-weed, and beakrush, are also spread when planting rice seed. Once weeds infest a ricefield, they are difficult to control.

The ricegrowing States have regulations on the sale and distribution of certified or registered seed that contain noxious weed seeds. Seed-certification programs provide for inspecting seed fields and harvested seed for the presence of weed seeds as well as for other aspects of seed quality. The seeding of rice seed grown under certification standards is a sound practice of weed control.

The use of herbicides to control weeds in the rice crop helps in the production of weed-free seed. The use of propanil to control barnyardgrass, brachiaria, and other annual grasses and the use of phenoxy herbicides to control curly indigo, sesbania, Mexican-weed, umbrellasedge, spikerushes, beakrush, and other broadleaf and sedge weeds can reduce weed-seed infestations in rice seed.

Crop Rotations

Properly managed rotations combined with use of herbicides are important for controlling weeds in rice. Weed competition in rice is effectively reduced in Louisiana and Texas by a rice-pasture rotation, and in Arkansas by a rice-soybean-oat rotation. To obtain maximum benefits during the year rice is grown, all crops in the rotation must be kept weed free.

In Louisiana and Texas a rice-pasture rotation reduces infestations of red rice, sesbania, curly indigo, Mexican-weed, cattails, bulrush, and many species of annual sedges. If sesbania, curly indigo, Mexican-weed, or annual sedges infest the pasture crop they should be controlled by timely applications of phenoxy herbicides. Although the rice-pasture rotation controls many species of weeds, it does not control barnyardgrass satisfactorily.

In Arkansas, rice-soybean-oat or rice-soybean rotations significantly reduce infestations of barnyardgrass, sesbania, curly indigo, ducksalad, spikerushes, umbrellasedges, and other weeds. The soybean crop in a rice-soybean-oat rotation can be kept weed free by combining cultural practices with use of preemergence herbicides. The oat crop can be kept free of broadleaf weeds by the use of 2,4–D or MCPA. The land may also be summer-fallowed after oat harvest to control weeds not controlled in the soybeans and oats. Summer fallow is especially effective in controlling barnyardgrass.

Crop rotation experiments at Stuttgart, Ark., from 1931 through 1940 showed that rice and cultivated soybeans planted in alternate years significantly reduced grass, broadleaf, and sedge weeds in the rice crop when compared with rice cropped continuously (*64*). Barnyardgrass was one of the main weeds in this experiment. Furthermore, barnyardgrass and other weeds were most effectively controlled with a crop rotation consisting of 1 year of rice followed by 2 years of cultivated soybeans.

Crop rotations coupled with hand pulling of scattered plants are important in controlling red rice. Pasture; cultivated row crops, such as soybeans, grain sorghums, and cotton; and summer and fall fallowing after harvest of a small grain crop are rotation practices that reduce problems with red rice in the rice crop.

Rotations of rice with an unirrigated row crop, such as safflower, or with fallow are valuable in California for reducing populations of cattails, bulrush, spikerush, and other perennial weeds with large rootstocks. For fallow to successfully control these weeds, the soil must be dried to a depth of 12 inches.

The combination of crop rotations and use of herbicides is more effective in controlling weeds in rice than either practice used alone. Preemergence and postemergence herbicides applied on row and pasture crops rotated with rice also reduce weed populations in the rice crop. Likewise, propanil and phenoxy herbicides used to control grass, broadleaf, and sedge weeds in the rice crop reduce weed infestation in the crops rotated with rice as well as in the rice crop.

Land Leveling and Levee Construction

Land leveling, combined with construction of levees to permit uniform depth of irrigation, is important in a weed-control program. Land leveling permits maintenance of a uniform depth of water on the field and allows adequate surface drainage. Land used for rice should be devoid of hummocks, ridges, sloughs, and hollows.

Aquatic weeds, including umbrellasedge, spikerush, ducksalad, algae, gooseweed, cattails, and bulrush, are most numerous in low areas where surface drainage is inadequate. Other weeds, including barnyardgrass, sesbania, and curly indigo, may be a problem on the ridges where water does not cover the land adequately. Therefore, land leveling and levee construction to eliminate low and high areas in the ricefield and to maintain 4 to 8 inches of water on the ricefield reduce problems with weeds. In addition, leveled land requires fewer levees; this facilitates control of grass and broadleaf weeds on the levees, which are ideal places for growth and reproduction of weeds. Elimination of levees reduces reinfestation areas for weeds.

Research in Arkansas and California has shown that plastic levees may be used satisfactorily in ricefields to control water (*38, 57*). Plastic levees help control grass and broadleaf weeds because they eliminate the need of soil levees where weeds grow and produce seed that fall onto the soil or water and reinfest the ricefield. Barnyardgrass, brachiaria, sesbania, curley indigo, morningglory, and smartweed are serious problems on soil levees. But methods have not yet been developed for adopting plastic levees to general field usage.

Herbicides reduce problems with weeds on ricefields with improper land leveling. Silvex, 2,4–D, 2,4,5–T, and MCPA control weeds, such as umbrellasedge, spikerush, ducksalad, gooseweed, and bulrush, that are associated with low or wet areas in the ricefield. Likewise, propanil reduces barnyardgrass infestations, and 2,4–D, 2,4,5–T, and silvex control sesbania and curly indigo infestations that are associated with high areas in the ricefield where 4 to 8 inches of water cannot be maintained. Weed infestations of barnyardgrass, sesbania, curly indigo, and smartweed on levees are reduced by herbicides, such as propanil, 2,4–D, 2,4,5–T, MCPA, and silvex.

Seedbed Preparation

One of the primary aims of seedbed preparation is to eliminate weeds. The seedbed may be prepared in many ways—plowing, disking, harrowing, rotary tilling, and combination methods. The best method to use depends on the soil, rotation, previous crop, seeding method, and perhaps other conditions. Regardless of the method used, the seedbed should be prepared to eliminate all weed growth at the time of seeding rice. When a rotation includes a spring-harvested crop, the land may be prepared during the summer and fall by repeated and timely cultivations or diskings to rid the field of many weeds. Then just before seeding rice in the spring the soil should be disked or harrowed to eliminate all weeds.

Thorough seedbed preparation helps to control all weeds that infest ricefields. By killing the weeds when preparing the seedbed, the weeds must germinate from seed or must emerge from root or stem parts after the rice is seeded. They are young and in the seedling stages during the early part of the rice-growing season. Herbicides may be used more effectively on young weed plants than on older established ones. Thorough seedbed preparation to rid the field of all weeds just before seeding the rice crop increases the effectiveness of herbicides used after the rice crop germinates and emerges.

Repeated cultivations in the spring at 1- to 3-week intervals before seeding rice reduces barnyardgrass and other annual grass infestations. The last cultivation should be shallow—usually not more than 2 or 3 inches—so that viable seed will not be brought near the surface of the soil. This method is not effective on aquatic species, such as ducksalad, redstem, spikerush, umbrellasedge, and algae. Seeding rice on a roughly prepared seedbed, especially on heavy clay soils, discourages germination of barnyardgrass, umbrellasedge, spikerush, redstem, waterplantain, burhead, and seedling cattail. In California, thorough plowing followed by complete drying of soil before seeding rice in water controls established plants of cattail, spikerush, and knotgrass. This method is ineffective in the southern rice-producing areas because spring rains prevent sufficient drying of the soil to kill the weeds.

Seeding

Rice may be drill seeded, sown broadcast on dry soil and disked or harrowed to cover, or sown in water by aircraft. Barnyardgrass is difficult to control by cultural or mechanical methods on drill-seeded or dry-broadcast-seeded rice. Seeding rice in water, therefore, was started in California to control barnyardgrass (*1*). This method reduces most infestations of barnyardgrass by inhibiting germination and growth. Investigations at Biggs, Calif., in which pot culture methods were used, indicated that common varieties of barnyardgrass seeded on puddled soil emerged to a 100-percent stand and those submerged 2, 4, 6, 8, or 10 inches emerged to a 10-, 5-, 1-, 0-, and 0-percent stand, respectively (*48*). Submergence not only reduced barnyardgrass infestations but it also delayed germination and emergence. However, some varieties of barnyardgrass germinate in submerged soil. In the pot-culture experiments at Biggs, Calif., white barnyardgrass emerged when submerged to a depth of 10 inches, although flooding did delay emergence (*48*).

Propanil effectively controls barnyardgrass in ricefields where deep water cannot be maintained. Propanil also controls white barnyardgrass, which is not controlled by deep water.

In a field experiment in California in 1956 (*33*), rice yielded 5,500 pounds per acre; and weeds, such as barnyardgrass and spikerush, were controlled where water was held all season at a depth of 6 inches. Where the water was lowered from 6 inches to 2 or 3 inches at 2, 3, and 4 weeks after seeding, rice yielded 3,500, 2,900, and 3,800 pounds per acre, respectively. Where the water was lowered at 2 weeks, barnyardgrass infested the plots. When the water was lowered at 3 or 4 weeks, barnyardgrass was controlled but spikerush infested the plots and reduced the yield of rice. Where deep water cannot be maintained on the rice for extended periods, herbicides can be used to control weeds. If barnyardgrass infestations develop after water has been lowered or drained from ricefields, they can be controlled with propanil. If spikerush infestations develop, they can be controlled with 2,4–D, 2,4,5–T, or MCPA.

Because rice usually germinates and grows well under 4 to 8 inches of water, water seeding may be used to selectively control barnyardgrass, brachiaria, sesbania, curly indigo, and sprangletop, provided the water can be held on the rice for 3 to 4 weeks after seeding. Sometimes, however, the water level must be lowered because the water stretches and weakens the rice plant. Lowering or draining the water allows germination of many weeds, such as barnyardgrass, curly indigo, sesbania, sprangletop, and spikerush. Conversely, water maintained on the ricefield for several weeks after seeding intensifies problems with certain aquatic weeds, such as ducksalad, waterhyssop, and algae. Barnyardgrass can be controlled with propanil. Ducksalad and waterhyssop can be controlled with 2,4–D or MCPA. Herbicides, therefore, are essential to effectively control weeds that may develop under any seeding method.

In California, water seeding is practiced on about 95 percent of the rice acreage to control barnyardgrass, spikerush, and sprangletop. In Southern ricegrowing areas, water seeding is practiced on about 25 percent of the acreage to control barnyardgrass. In California, if late spring rains germinate barnyardgrass seed before rice is planted, the field must be cultivated to kill barnyardgrass seedlings. The soil should then be thoroughly dried before flooding and seeding to prevent algae from infesting the field.

Water Management

Flooding rice to a depth of 4 to 8 inches when it is in the seedling stage reduces infestation of barnyardgrass. The barnyardgrass should be in the 1- to 3-leaf stage, and water should remain on the field 1 to 3 weeks to kill it. High water temperatures (95° F. or above) facilitate control of barnyardgrass, presumably because of the low oxygen content of warm water. Rice may be stretched and weakened by 4 to 8 inches of water. Water temperatures of 95° or above may also injure the rice. When only hard water—such as water pumped from shallow wells in certain areas of Arkansas—is available, young rice may be injured severely by deep and prolonged flooding even where water temperatures are optimum. Early flooding to control grass weeds, therefore, has a narrow margin of selectivity and must be used with caution. Herbicides used in combination with water management practices control weeds more effectively than either practice alone.

Timely and thorough draining of the water from the ricefield helps control many aquatic weeds, including algae and ducksalad. Experiments in Arkansas showed that algae, or "scum," may be controlled by lowering or draining water from the field as soon as green areas of algal growth appear on the soil (*69*). Water may be manipulated on and off the field to keep algal growth at a minimum until the rice plants are large enough (12 to 18 inches tall) to be unaffected by the algae.

Young ducksalad and other aquatic weeds (either emersed or submerged) are effectively controlled by draining the flood water from the field. The soil must become thoroughly dry to control these weeds, but rice will also be injured if the soil becomes "sunbaked."

When draining a ricefield, care must be exercised to prevent germination, emergence, and infestations of barnyardgrass. Early in the season, or during the algal-growth period, water left off the field for more than 3 or 4 days allows grass weeds, particularly barnyardgrass, to infest the ricefield. The water, therefore, must be manipulated to control algae, to prevent desiccation of rice, and to forestall germination or emergence of barnyardgrass. Accomplishing all these is difficult in commercial ricefields.

Herbicides may be combined advantageously with water management practices. Combination treatments with herbicides, such as propanil and 2,4–D, are changing water management practices in rice production in the West and in the South. A water depth of 6 inches or more is used primarily to control barnyardgrass in California (*105*). The use of propanil and other herbicides, such as 2,4–D and MCPA, to control weeds is having a revolutionary impact on rice culture, including seedbed preparation, levee construction, timing and methods of seeding, fertilizer practices, and water management. Chemical weed control thus offers unusual opportunity for water conservation and lowering the cost of rice production.

Fertilizer Management

Phosphate and nitrogen applied directly to rice stimulate growth of many weeds, including barnyardgrass, ducksalad, and algae, but potash applied directly to rice apparently has little or no effect on the growth of weeds.

Phosphate

Time and method of applying phosphate are very important when barnyardgrass and other grass-weed seeds infest ricefields in southern ricegrowing areas. Phosphate applied before dry seeding rice stimulates growth of young plants of barnyardgrass. Where fields have a history of severe infestation of barnyardgrass, phosphate should be applied to a crop in the rotation other than rice or treatment should be delayed until just before the rice is inundated the first time. Broadcasting phosphate on the soil surface combined with incorporating it in the top 2 or 3 inches of soil stimulates growth of grass weeds. When applications of phosphate are required before planting rice, it should be applied several inches below the rice seed while drilling. It should not be applied broadcast before seeding rice in dry soil, but it may be applied just before the first watering without stimulating grass weeds on ricefields not infested with barnyardgrass. Phosphate should not be applied to standing water because it stimulates algae or other aquatic weeds or may be used ineffectively by the rice.

In California, phosphate is applied to thoroughly dry soil, the field is flooded, and then the rice is seeded. Phosphate applied before seeding enables the rice plants to grow rapidly and to compete better with grass weeds. Herbicides, such as propanil and MCPA, can reduce weed infestations on ricefields where phosphate has stimulated weed growth.

The soil in many ricefields in the South is low in available phosphate (*12, 109*). These soils require supplemental applications of phosphate fertilizers for rice production. Phosphate requirements of annual plants are relatively heavy during the first few weeks after germination (*61*). In southern rice-producing areas, phosphate is applied to crops in the rotation and not to the rice to reduce grass-weed infestations. Conceivably, this practice could result in a phosphate deficiency during the early stages of rice development when phosphate is needed most by the rice plant. The use of herbicides to control grass weeds will require a re-evaluation of phosphate requirements and of application practices in rice production. Perhaps where herbicides are used to control grass weeds, the rice plants can use phosphate more efficiently if it is applied before planting rather than at other times.

Nitrogen

Time of applying nitrogen to rice is important in preventing losses in rice yield due to barnyardgrass competition. In Arkansas, nitrogen applied to dry-planted rice before seeding stimulates growth of barnyardgrass. When rice was heavily infested with barnyardgrass, application of nitrogen at the heading stage of barnyardgrass reduced competition. Application of nitrogen at the vegetative stage of the grass enhanced competition of grass with rice (table 4).

The 1963 nitrogen recommendations for rice production by the Arkansas Agricultural Extension Service were different where grass weeds were absent or controlled than where they were present. For example, on a midseason variety, such as Bluebonnet 50, where 65 pounds or more per acre of nitrogen was required, the recommendations were:

(1) Where grass is a problem, apply one-half of the nitrogen after grass begins heading, or about 50 days but not later than 60 days after rice emergence, and

apply one-half 10 days later. (2) Where grass is not a problem or is controlled with herbicides, apply one-half of the nitrogen 15 days after rice emergence or before the first flooding and one-half 65 days after rice emergence.

Under California conditions, however, delayed nitrogen fertilization does not aid in controlling weeds.

TABLE 4.—*Effect of time and rate of application of nitrogen on yield of rice heavily infested with barnyardgrass, Stuttgart, Ark., 1957 and 1959*

Stage of barnyard-grass when nitrogen was applied[1]	Rate of nitrogen per acre	Yield of rice per acre		
		1957	1959	Average
	Pounds	*Pounds*	*Pounds*	*Pounds*
Untreated check	None	2,090	1,900	1,990
Heading	60	2,900	1,780	2,340
	120	3,270	2,730	3,000
	180	3,470	3,380	3,430
Mature	60	2,390	1,840	2,120
Vegetative and heading[2]	120	2,360	1,370	1,860
Vegetative and mature[2]	120	2,500	1,530	2,010
Heading and mature[2]	120	3,070	2,470	2,770
L.S.D. at 5-percent level		900	720	810
L.S.D. at 1-percent level		1,200	950	1,080

[1] Vegetative, heading, and mature stages were 3, 8, and 12 weeks after emergence of rice and barnyardgrass.
[2] 60 pounds per acre applied at each stage.

In California and in southern ricegrowing areas where rice is water seeded, nitrogen may be applied before seeding. In southern ricegrowing areas, this treatment stimulates growth of aquatic weeds, such as ducksalad, waterhyssop, algae, spikerush, and umbrellasedge. Nitrogen applied to standing water stimulates the growth of weeds and reduces efficient utilization of nitrogen by rice. If nitrogen stimulates excessive weed growth, herbicides, such as propanil, 2,4–D, MCPA, 2,4,5–T, and silvex, can be used to reduce weed infestations.

Herbicides, such as propanil, 2,4–D, and 2,4,5–T, reduce problems with barnyardgrass and broadleaf and sedge weeds by reducing weed competition in rice. Where herbicides are used, nitrogen applications can be managed efficiently and the rice plant can use nitrogen effectively.

Cultivation

Weed control in Asia, including such countries as India, Indonesia, Korea, the Philippine Islands, Taiwan, and Thailand, consists mainly of hand weeding. The rice is transplanted in rows to facilitate hand-weeding practices. The weeds are pulled by hand and piled on the levees or buried with the hands and feet in the soft, muddy soil. Sometimes hand tools, such as knives, hoes, and machetes, are used to destroy the weed growth. In Japan, weeds are controlled by mechanical methods as well as by hand weeding. Rotary and basket-shaped weeders driven by hand, animal, or power are directed between the rows to cut, bury, and kill weeds.

In the United States, cultivation methods other than rotary hoeing to remove weeds after the crop is seeded are just about nonexistent in rice culture. In drill-seeded rice, "weeding" or cultivation between rows to remove weeds is limited; and if rice is dry broadcast or water seeded, cultivation to control weeds is not possible.

Dry-seeded rice may be cultivated with a rotary hoe in some production areas. It must be cultivated soon after emergence and while the weeds are very small. The soil must contain the right amount of moisture; it must be neither too dry nor too wet. Rotary hoeing seldom controls weeds because timing and soil conditions are so critical.

CHEMICAL METHODS OF WEED CONTROL

Chemical control of broadleaf weeds in rice began with the use of 2,4–D. In 1963 more than half of the rice crop was sprayed to control broadleaf weeds.

CIPC was used in 1960 and 1961 in Arkansas to control grass weeds in rice. It was used on only a small acreage because of the critical requirements for effective weed control without crop injury. It had to be applied when grass weeds were in the 1- to 2-leaf stages of development, on rice seeded 1 to 2 inches deep in the soil, and when moisture was adequate to activate the herbicide.

The first experiments in Arkansas with propanil in 1959 showed that it effectively controlled certain young grass and broadleaf weeds in rice. Propanil was very selective, and early postemergence treatments at high rates (8 to 10 pounds per acre) did not injure rice. Rice farmers in cooperative trials with commercial chemical companies used propanil in commercial fields in 1961 on about 20,000 acres (*15*).

In 1962 propanil was recommended by the Agricultural Experiment Stations in Arkansas, Mississippi, and Texas, and farmers treated approximately 250,000 acres. Good to excellent grass and weed control and significant improvement in yields were obtained on more than 90 percent of the fields treated (*16*). In 1963 and 1964 propanil was used by rice farmers on more than 50 percent of the rice acreage.

Herbicides

Many herbicides are used to control weeds in rice, and many others are being evaluated experimentally to determine their usefulness. Only those of current general interest and usefulness are described in this handbook.

Phenoxy Herbicides

Phenoxy herbicides, such as 2,4–D, MCPA, 2,4,5–T, and silvex, are used as postemergence selective herbicides to control broadleaf weeds in rice.

Phenoxy herbicides usually are formulated and marketed as two basic types—salts and esters. They are low to intermediate in oral toxicity (LD_{50} = 375 to 1,200 milligrams per kilogram).[3]

The most widely used salts of 2,4–D, MCPA, and 2,4,5–T include such amines as diethanolamine, triethanolamine, alkanolamine, dimethylamine, triethylamine, and isopropylamine. These amine salt formulations are available chiefly as water soluble liquids and are practically nonvolatile, which makes them much safer than ester formulations to use near valuable susceptible plants.

Esters of the phenoxy herbicides are high or low volatile. The high-volatile esters include methyl, ethyl, isopropyl, butyl, and amyl. The low-volatile esters include the butoxyethanol, butoxyethoxypropanol, capryl, ethoxyethoxypropanol, isooctyl, and propylene glycol butyl ether. These esters of 2,4–D, MCPA, 2,4,5–T, and silvex are liquids which, when properly formulated, form oil-in-water emulsions. In areas near susceptible crops, low-volatile esters are less hazardous than high-volatile ones when temperatures are 95° F. or less. When temperatures exceed 95°, the vapors of even the low-volatile esters may injure susceptible crops. Ricegrowing States have laws prohibiting the use of high-volatile esters, but low-volatile esters of 2,4–D, MCPA, 2,4,5–T, and silvex may be used to control broadleaf weeds in rice.

Carbamates

Although CIPC has had limited usefulness for weed control in rice, it is the only carbamate cleared for such use. However, the carbamates include several newer herbicides, such as swep and molinate (discussed under New Herbicides), which show considerable promise. Carbamates are relatively insoluble in water but may be formulated with organic solvents as emulsifiable concentrates to provide oil-in-water emulsions for low- or high-gallonage applications. Carbamates are moderately volatile, and their activity may decrease rapidly at high temperatures. Activity may also decrease at high soil moistures. Oral toxicities of carbamates to rats are low; LD_{50} values range from 720 to 5,000 milligrams per kilogram of body weight.

Propanil

Propanil is relatively insoluble in water, but it is formulated with organic solvents as an emulsifiable concentrate. It forms oil-in-water emulsions and is slightly volatile at high temperatures. It has low oral toxicity for rats; the LD_{50} ranges from 1,200 to 2,300 milligrams per kilogram of body weight.

New Herbicides

Research is being continued to improve current weed-control practices and to develop new herbicides and new, improved chemical-cultural methods of controlling weeds in rice. Three herbicides that recently have shown outstanding experimental performance for controlling grass weeds in rice are swep, molinate, and 4-chlorobenzenesulfono-2-toluidide. They have not been approved for use on rice.

Swep gives both preemergence and early postemergence control of many grass and broadleaf weeds, including barnyardgrass, brachiaria, crabgrass, sesbania, curly indigo, and Mexican-weed. Swep was most effective when applied at rates of 4 to 6 pounds in 10 to 20 gallons of water per acre. Higher application rates were harmful to the rice crop, and lower rates did not control the grass weeds.

Swep controlled grass weeds best when applied to grass plants having 1 or 2 leaves. Treatment immediately after seeding was less effective than treatment at weed emergence. Young rice plants were tolerant to swep, but older ones (those with two or more leaves) were sometimes injured.

[3] The symbol LD_{50} means the lethal dosage that kills 50 percent of the experimental animals; the dosage is expressed as milligrams of substance per kilogram of body weight.

Swep controlled grass weeds for 10 to 14 days after spraying if the soil contained enough moisture to activate the swep. When sprayed onto barnyardgrass in the 1- to 2-leaf stages, it killed the plants that were up and controlled barnyardgrass that emerged during the following 10 to 14 days. Flooding at the end of this period was necessary to prevent barnyardgrass emergence and reinfestation.

Commercially grown varieties of rice are tolerant to swep. Field experiments indicated that swep injured dry-seeded rice (drilled or broadcast) less than water-seeded rice.

Molinate controlled barnyardgrass in experiments in California and Arkansas. In California, molinate at 2 to 12 pounds per acre applied as a preplant soil-incorporated treatment effectively controlled barnyardgrass and did not injure rice. Emulsifiable concentrate and granular formulations of molinate controlled barnyardgrass effectively, if the soil was dry at treatment. Soil incorporation or flooding within 12 hours after application prevented loss of the herbicide from the soil by volatilization. If the soil was moist at treatment, the herbicide had to be incorporated immediately after application to prevent loss from the soil. In Arkansas, preplant soil-incorporated applications of molinate at 2 to 8 pounds per acre controlled barnyardgrass but injured rice somewhat. Postemergence water-applied treatments of granular molinate at 4 pounds per acre effectively controlled barnyardgrass and did not injure rice. In this experiment molinate was broadcast onto the water when barnyardgrass plants had 2 or 3 leaves and the rice had 1 or 2 leaves.

Investigations in Arkansas indicated that 4-chlorobenzenesulfono-2-toluidide controls barnyardgrass and other grass weeds when applied before they emerge. Application rates of 4 to 6 pounds per acre controlled grass weeds effectively and did not injure rice. Grass weeds were controlled most effectively when the herbicide treatment was followed immediately by flooding. Barnyardgrass sprayed with 4-chlorobenzenesulfono-2-toluidide turned red 3 to 7 days after treatment.

General Precautions for Using Herbicides

Drift Hazards

PHENOXY HERBICIDES.—Caution should be used when spraying 2,4–D, MCPA, 2,4,5–T, and silvex to control broadleaf weeds in rice since these herbicides are very toxic to crops, such as cotton, soybeans, and tomatoes, and to valuable trees, shrubs, and ornamental plants. These herbicides should not be sprayed when the wind is blowing more than 5 miles per hour. Ricegrowing States specify wind-velocity limits for tractor and aerial spraying.

Cotton and soybeans are injured more severely by some phenoxy herbicides than by others. Cotton is injured most severely by 2,4–D, followed by MCPA, silvex, and 2,4,5–T in decreasing order. Soybeans are injured most severely by silvex, followed by 2,4,5–T and 2,4–D in decreasing order. Cotton and soybeans are normally injured less by amine salt formulations of phenoxy herbicides than by esters.

Spray from amine salts and low-volatile esters usually drifts to susceptible crops or plants during the spraying operation and not afterward. At temperatures above 95° F., low-volatile ester formulations may volatilize after spraying. The vapors may injure nearby susceptible crops.

All major rice-producing States regulate aerial spraying of phenoxy herbicides. Most States also regulate ground applications. Before spraying rice with postemergence herbicides, farmers and custom applicators should become familiar with State regulations concerning equipment, herbicide formulations, wind velocity, records, responsibility, and liability.

PROPANIL.—Field crops, such as cotton and soybeans, and certain horticultural and ornamental plants are injured by spray drift of propanil. Propanil is not so toxic to these plants as phenoxy herbicides, but spray drift to nearby susceptible plants should be prevented. Application of propanil by aerial equipment causes greater drift than application by ground equipment. When aerial equipment is used, special attention should be given to wind velocity and direction to avoid spray drift on nearby susceptible plants. Spraying is best when wind velocity is not more than 5 miles per hour. Propanil should not be sprayed when wind velocity exceeds 10 miles per hour. If the susceptible crop is located upwind from the rice, spraying may be done safely in a 1 to 10 mile per hour wind within 100 to 200 feet of the susceptible crop. If the sensitive crop is downwind from the rice, the safe distance is at least one-half mile.

Propanil may kill young cotton and soybean plants and severely injure older ones. Cotton and soybean plants are very susceptible to propanil from the time they emerge until they are 8 to 10 inches tall. Usually one-half pound per acre is required to injure them severely enough to reduce yields greatly. Propanil injury on cotton and soybean plants appears as brown and yellow mottling on the leaves, and as necrosis along leaf margins; often the leaves and whole plants are killed. If the plants are not killed, they usually grow new leaves, recover vegetatively, and produce nearly normal yields. Older plants recover more quickly and completely than do younger ones.

Residue Hazards

In addition to State laws regulating application of herbicides, Federal laws provide for establishing safe tolerances for residues of herbicides on raw agricultural products. Both rough and milled rice are classed as raw agricultural products. Herbicides that leave no residue may be used on rice without regard to the tolerance. Propanil, 2,4–D, MCPA, 2,4,5–T, silvex, and CIPC leave no residue if used according to directions on the label.

The directions for using a pesticide, which appear on the label, are subject to clearance under a Federal law known as the Insecticide, Fungicide, and Rodenticide Act. Clearance is withheld if, on the basis of experimental evidence, the usage proposed may contribute residue in excess of the applicable tolerance. In the event no tolerance or exemption exists for the pesticide, clearance is withheld if the proposed usage would likely contribute any residue. The joint opinion of the Pesticides Regulation Division of the U.S. Department of Agriculture and of the Food and Drug Administration of the Department of Health, Education, and Welfare is that labels of pesticides in commercial usage should generally furnish a reliable guide so as to avoid excessive residues (*107*).

Storage

A herbicide with a low flash point (140° F. or less) is dangerous in storage. Herbicides used for weed control in rice have relatively high flash points; hence, they may be stored safely without hazard of fire.

Deterioration of herbicides in storage can be prevented by observing certain precautions. Dust and wettable powders should be stored in a dry place. If they get wet, they may cake and the packages may deteriorate. Water-soluble solids also may cake when wet and when subjected to great changes in temperature. If packages are left open, hygroscopic chemicals become wet by absorbing water from moist air. It is essential, therefore, to close herbicide packages tightly for storage.

Liquid formulations should be stored on pallets or duckboards to prevent rusting of the metal containers. Containers should be kept closed tightly and air vents—punched to facilitate pouring—should be plugged. Small amounts of water introduced into emulsifiable concentrates or oil solutions may cause the solution to jell or may cause deterioration of the container.

Liquid herbicides may crystallize or precipitate at temperatures below 32° F. If this happens, the solution should be heated to 40° or slightly higher, and the containers should be rolled or shaken. If the crystals return to solution, the herbicide is then usually good; but the herbicide should not be used if the crystals do not dissolve. Phenoxy herbicides and propanil should not be stored at temperatures below 15°.

Liquid herbicides may deteriorate at temperatures above 95° F. In addition, herbicides stored in drums may expand at high temperatures and cause bulging and leaking of the containers. High temperatures also may reduce the effectiveness of emulsifiers and hasten the corrosion of containers. Drums of herbicides stored in the direct sun become excessively hot, especially during hot weather. Herbicides should be stored in well-ventilated buildings or sheds during hot weather.

Safety in Handling

Herbicides used for commercial weed control in rice are relatively nontoxic to humans and warm-blooded animals. Caution, however, should be used when mixing, applying, or disposing of herbicides to prevent contact with the herbicide. Propanil may be especially irritating to the skin and eyes. If the concentrated herbicide is accidentally spilled on the skin or in the eyes, the skin or eyes should be flooded promptly and thoroughly with water.

The spray mixture may be irritating, especially to the eyes. Mixing crews, flagmen, and applicators should avoid breathing fumes and spray mist and should be careful that the spray does not come in contact with the eyes and skin. If repeated and prolonged exposure is likely, goggles and protective clothing should be worn.

To protect fish and wildlife, care should be taken not to contaminate ponds, lakes, or streams while mixing, applying, or disposing of herbicides. Herbicides should not be stored near feed or food.

Cleaning Spray Equipment

Spray equipment used to apply phenoxy herbicides should not be used to apply other chemicals to cotton, tomatoes, or other plants because these herbicides are difficult to remove from the sprayer and even traces left in the sprayer will cause serious damage. After thorough cleaning, however, the same sprayer used for phenoxy herbicides may be used to apply fungicides, insecticides, and other herbicides on moderately sensitive crops, including soybeans, clover, and lespedeza.

Thorough cleaning of a sprayer with warm water and a detergent should remove most of the herbicide remaining in the sprayer. Further cleaning may be accomplished with a solution of 1 part household ammonia in 100 parts of water. This solution should remain in the tank, including hose and boom, for 12 to 24 hours. The equipment then should be thoroughly rinsed with clean water.

Activated charcoal is one of the most effective agents for cleaning herbicides from spray equipment. It has the advantage of being a faster and more effective cleaning agent than household ammonia. Phenoxy herbicides can be removed by rinsing the sprayer for about 2 minutes with a 1-percent suspension of activated charcoal followed by a rinse of clean water. A desirable solution may be made by mixing 1 pound of finely ground activated charcoal in 12 gallons of water containing a detergent.

To be sure the sprayer contains no herbicide, the operator may fill the sprayer with water and spray seedlings of a sensitive plant, such as bean, tomato, or morningglory. If the seedlings are not affected within 1 or 2 days, the equipment is safe for further use.

Spray equipment used for propanil can be used safely for other spraying purposes if all parts are cleaned thoroughly with water and detergent and then rinsed several times with clean water. All parts of the sprayer, including hose, pump, boom, and nozzles, should be cleaned thoroughly.

Principles of Controlling Weeds With Herbicides

Controlling Grass and Broadleaf Weeds With Propanil

Propanil controls barnyardgrass, including species of *Echinochloa crusgalli*, *E. colonum*, and *E. cruspavonis*, and other grasses, including crabgrass (*Digitaria* spp.), Texas-millet (*Panicum texanum* Buckl.), paragrass (*P. purpurascens* Raddi.), and brachiaria. Propanil also controls certain young annual broadleaf weeds, such as sesbania, curly indigo, gooseweed, redstem, and waterplantain, and young annual sedges, such as spikerush, umbrellasedge, fimbristylis, and rough-seed bulrush. These weeds are most effectively controlled when they are in the early vegetative stage of growth.

Mode of Action.—Propanil is a selective postemergence herbicide for grass and broadleaf weeds. It is usually applied when the weeds and rice are in the early stages of development. Propanil apparently kills the cells of grass and broadleaf plants by contact action. Investigations in the United States with a radioactive isotope indicated that propanil was not translocated appreciably either upward or downward in either rice or barnyardgrass (*58*). Work in Japan, however, showed that propanil was translocated rapidly upward but slowly downward (*101*). Propanil applied to leaf apexes of barnyardgrass killed only the cells at the leaf tip, but that applied to the leaf sheath killed the treated leaf and subsequent new leaves. This may explain the need for completely covering the grass plants in field treatments. Propanil activity on barnyardgrass progressed from cell to cell in an apical direction (*101*).

Absorption and translocation differences in rice and barnyardgrass do not explain the basis of selectivity of propanil. The basis of selectivity is undoubtedly physiological or biochemical.

Rate of Application.—Propanil at 3 to 4 pounds per acre applied at the correct time controls most annual grass weeds (fig. 1). In a field experiment in Arkansas, propanil at 3, 5, and 7 pounds per acre was applied to barnyardgrass having 2 or 3 leaves (fig. 2). Barnyardgrass having 2 or 3 leaves was controlled well enough with 3 pounds of propanil to produce nearly maximum yields of rice (table 5). In another investigation in Arkansas, propanil at 2 pounds per acre applied to barnyardgrass having 1 to 3 leaves gave somewhat less control than did rates of 3 pounds or more (table 6).

Results from these experiments in Arkansas are indicative of experimental results obtained from California, Louisiana, Mississippi, and Texas.

A temporary chlorosis and tipburn on rice leaves may occur soon after treatment with propanil at rates of 3 or 4 pounds per acre, but no permanent injury to rice occurs even with rates as high as 12 pounds. New leaves that emerge after treatment normally show no signs of injury. Injury on rice is more pronounced and persists longer when the soil is very dry and when temperatures are either extremely low (daily lows below 50° F.) or extremely high (daily highs above 95°) at the time of treatment; but even when injury is pronounced, rice plants outgrow damage within 5 to 10 days after treatment.

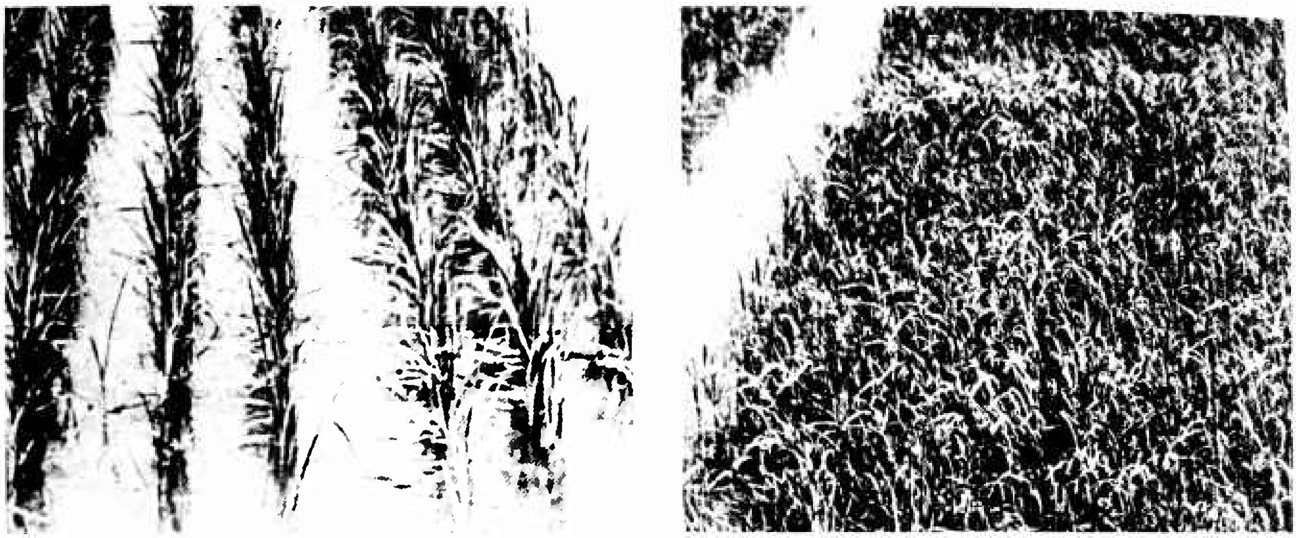

FIGURE 1.—Control of barnyardgrass in rice with propanil: *Left,* Plot sprayed with propanil at 4 pounds per acre when barnyardgrass had 2 or 3 leaves; *right,* unsprayed plot.

FIGURE 2.—Growth stages of barnyardgrass: *Left to right,* Plants in the 1-, 2-, 3-, 4-, and 5-leaf and tillering stages.

TABLE 5.—*Effect of time and rate of application of propanil on control of barnyardgrass and yield of rice grown in the field, Stuttgart, Ark., 1960*

Stage or height of grass at time of spraying	Control of barnyardgrass				Yield of rice, per acre			
	When rate of propanil applied per acre was—			Average	When rate of propanil applied per acre was—			Average[1]
	3 pounds	5 pounds	7 pounds		3 pounds	5 pounds	7 pounds	
	Percent	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Immediately after seeding	17	18	15	17	2,320	2,660	2,930	2,640
1-leaf, ½ inch	58	52	64	58	4,100	3,720	4,100	3,970
2- and 3-leaf, 2 inches	80	84	88	84	4,640	4,700	4,630	4,660
L.S.D. at 5-percent level				8				330
L.S.D. at 1-percent level				11				440

[1] The hoed and unhoed checks yielded 4,720 and 2,640 pounds per acre, respectively.

TABLE 6.—*Effect of rate of application of propanil on control of barnyardgrass and yield of rice grown in the field at two locations in Arkansas, 1961*

[Propanil applied at early postemergence; barnyardgrass had 2 or 3 leaves]

Location of experiment and rate of propanil per acre	Control of barnyard-grass	Yield of rice, per acre[1]
	Percent	*Pounds*
Kelso:[2]		
None (check)	5	2,460
2 pounds	70	3,110
3 pounds	85	3,320
5 pounds	85	3,380
7 pounds	88	3,400
9 pounds	83	3,410
12 pounds	87	3,730
Keiser:[3]		
None (check)	5	3,490
2 pounds	70	3,840
3 pounds	78	3,700
5 pounds	86	4,000
7 pounds	91	3,860
9 pounds	96	3,930
12 pounds	99	3,590

[1] Propanil-treated plots yielded significantly more rice than the check, but yield from plots treated with different rates did not differ significantly.

[2] Propanil-treated plots had significantly less barnyardgrass, but control of barnyardgrass on plots treated with different rates did not differ significantly.

[3] L.S.D. for control of barnyardgrass: at 5-percent level, 10 percent; at 1-percent level, 14 percent.

TIME OF APPLICATION.—Propanil applied as a preplanting or a preemergence treatment does not control grass weeds or injure rice (table 5). It controls barnyardgrass most effectively when applied to grass in the 2- or 3-leaf stage, or 2 to 3 inches tall (fig. 2; tables 5 and 7). Propanil applied at 3 to 9 pounds per acre to barnyardgrass 6 inches tall or more usually does not control it satisfactorily. Rapid-growing and succulent grass weeds, however, may be controlled when they have 4 leaves or more. In a field experiment in 1961, barnyardgrass was controlled progressively less as it increased in size from ½ to 2 inches tall to 10 to 36 inches tall (table 7). Control of barnyardgrass also decreased in 1962 when propanil was applied during the first four stages of growth, but control was better when it was applied at the last two stages than when it was applied at the fourth stage (table 7). The high degree of control at the last two stages in 1962 was the result of an application of nitrogen immediately after the fourth treatment, which made the grass grow rapidly. Thus, rapidly growing grass, even though it was large, was more susceptible to propanil than was grass growing more slowly. The results of these experiments indicate the importance of the growth rate of weeds when propanil is used.

Grass weeds in the 1-leaf stage are killed by propanil, but plants that emerge afterward may reinfest the ricefield. For example, propanil gave only 58-percent control of barnyardgrass when applied to grass weeds in the 1-leaf stage (table 5). Emerged grass was killed, but that emerging after spraying reinfested the plots. Usually most of the grass weeds will have emerged by the time the oldest grass

TABLE 7.—*Effect of time of application of propanil on control of barnyardgrass and yield of rice, Stuttgart, Ark., 1961-62*

[Values are averages from plots treated with 3, 5, 7, and 9 pounds of propanil per acre]

Height or stage of grass at time of spraying	Control of barnyardgrass		Yield of rice, per acre	
	1961	1962	1961	1962
	Percent	*Percent*	*Pounds*	*Pounds*
½ to 2 inches, or 2- to 4-leaf	69	100	3,720	4,680
½ to 7 inches, or 2-leaf to early tillering	60	82	3,570	4,530
2 to 8 inches, or early tillering	48	50	3,440	3,950
6 to 13 inches, or late tillering	17	22	2,700	3,070
10 to 20 inches, or beginning to head	0	42	2,310	3,510
15 to 36 inches, or heading	10	46	2,530	3,380
Not sprayed (check)	0	0	2,340	2,010
L.S.D. at 5-percent level	11	16	440	890
L.S.D. at 1-percent level	16	23	630	1,060

reaches the 3-leaf stage. Because propanil has no preemergence activity, it should not be applied until all grass weeds have emerged.

Propanil should be applied according to the developmental stage of the grass weeds rather than the rice. When barnyardgrass has 2 or 3 leaves, rice usually has 1 or 2 leaves, but it may be just emerging or may have 3 leaves or more. However, there should be a reasonable stand of rice before treatment. If the crop has to be replanted for any reason, the propanil application will be wasted.

WATER MANAGEMENT.—Irrigating the ricefield before treatment with propanil may be necessary during dry, hot weather. In experiments in Arkansas in May 1962, rice was seeded when the soil had sufficient moisture for germination of rice and barnyardgrass. No rain fell from planting time until spraying time (11 days). The barnyardgrass seedlings were growing slowly in the dry soil, and many seedlings were not killed by propanil. Barnyardgrass plants with 1 to 3 leaves were usually killed even though they were growing slowly, but those with 4 or more leaves and those with tillers were not killed. When the soil is dry and crusty, irrigation of the ricefields a few days before spraying stimulates grass weeds and makes them more susceptible to propanil.

Water should not be standing on fields when they are treated with propanil. Weeds covered with water are not killed because propanil cannot contact them. Moist or puddled soil is desirable because grass weeds are presumably growing rapidly when moisture is adequate.

Fields treated with propanil should be flooded 1 to 4 days after treatment to prevent barnyardgrass or other grass-weed plants from reinfesting the field to compete with rice and cause severe yield losses. Flooding the ricefield immediately after treatment sometimes increases the activity of propanil on barnyardgrass.

Some commercial fields of rice are so large that timely flooding after treatment with propanil may be difficult. If all of a large field is sprayed at once, grass weeds may reinfest the field before it can be flooded, especially if the water supply is limited. Large fields should be divided so that they can be flooded with the available water supply on the farm within 1 to 4 days after spraying. Field size should be keyed to water supply before the rice is planted and not after the rice has emerged and is ready for spraying.

METHOD AND DEPTH OF SEEDING.—Propanil at 2, 4, 8, and 16 pounds per acre applied to varieties Bluebonnet 50 and Nato in the 1- and 2-leaf stages grown in the greenhouse at Stuttgart, Ark., did not injure either variety regardless of method or depth of seeding, but 32 pounds injured both varieties moderately (table 8). Field-grown Bluebonnet 50 that was sprayed with propanil when it was in the 1- to 2-leaf stage was not injured (table 9). Thus, method and depth of seeding rice do not affect the activity of propanil on rice.

METHOD OF APPLICATION.—Propanil may be applied in the field with ground or aerial equipment. Boom-nozzle sprayers are more satisfactory for ground applications than are other types of sprayers. Boom-nozzle, venturi, and rotary-atomizer sprayers, when properly adjusted and operated, are satisfactory for aerial applications. Aerial equipment is more satisfactory than ground equipment because quick and timely applications can be made even though the field may be too wet to support ground equipment. Moreover, levees present a problem with ground-operated equipment. Droplets from 200 to 400 microns in diameter are considered optimum for ground applications. Droplets that range from 200 to 300 microns in diameter while in the air are considered optimum for aerial applications.

The spray pattern of aerial and ground equipment should be checked carefully before spraying to insure uniform spray applications.

TABLE 8.—*Effect of method and depth of seeding of rice and rate of propanil as an early postemergence application on growth of two varieties of rice under greenhouse conditions, Stuttgart, Ark., 1959*

Variety and method and depth of seeding	Injury rating of rice when rate of propanil applied per acre was[1]—					
	0	2 pounds	4 pounds	8 pounds	16 pounds	32 pounds
Nato:						
Water seeding	0	0	0	1.3	1.7	6.0
Dry seeding, ½ inch	0	2	0	0	1.3	3.7
Dry seeding, 1½ inch	0	0	0	0	1.3	2.7
Bluebonnet 50:						
Water seeding	0	0	0	0	2.3	3.7
Dry seeding, ½ inch	0	0	0	.7	1.0	4.3
Dry seeding, 1½ inch	0	0	0	0	0	1.3

[1] Rated as follows: 0, no injury; 1-3, slight injury; 4-6, moderate injury; 7-9, severe injury; 10, all plants killed.

TABLE 9.—*Effect of method and depth of seeding of rice and rate of propanil as an early postemergence application on yield of Bluebonnet 50 rice grown in the field, Stuttgart, Ark., 1960*

Method and depth of seeding	Yield of rice, per acre[1]			
	Rate of propanil applied, per acre			Average
	3 pounds	6 pounds	12 pounds	
	Percent	*Percent*	*Percent*	*Percent*
Water seeding; soil surface	101	102	106	103
Drilling; 1½ inches	102	105	104	104
Broadcasting; ½ to 1¼ inches	108	105	109	107

[1] Yields expressed as percentage of weed-free check. Yields for water seeding, drilling, and broadcasting treatments in the untreated weed-free checks were 5,630, 5,310, and 5,220 pounds per acre, respectively.

When aerial equipment is used, the swath should be about equal to the wing span of the aircraft or, preferably, slightly less but it may vary with type of aircraft and spray equipment. A swath of 30 to 40 feet is generally used. Grass and broadleaf weeds are controlled satisfactorily with propanil when the spray solution covers the weeds adequately and uniformly.

SPRAY VOLUME.—Because of the mode of action of propanil, uniform coverage of the exposed part of grass and broadleaf weeds is necessary for satisfactory control. The same amount of chemical per leaf is more effective in many well-distributed droplets than in one large drop.

Ground sprayers should apply propanil at 3 or 4 pounds per acre in 15 to 20 gallons per acre of herbicide-water solution. In one field experiment in Arkansas, propanil at 3 pounds per acre applied by tractor-drawn equipment in spray solutions of 5, 10, 20, and 40 gallons per acre controlled barnyardgrass, and rice was uninjured at all volumes. Ground equipment in a field experiment in Texas, however, controlled 99 percent of the grass weeds when propanil at 3 pounds per acre was applied in a spray solution of 10 gallons per acre but only 90 and 66 percent at the same rate when applied in solutions of 8 and 5 gallons per acre. Other experiments and observations suggest that propanil at 3 or 4 pounds per acre applied by ground equipment controls barnyardgrass and broadleaf weeds more effectively when applied in herbicide-water solutions of 15 to 20 gallons per acre than when applied at lower volumes.

A spray volume of at least 10 gallons per acre of herbicide-water solution is generally used for aerial applications of propanil. A volume of 12 to 15 gallons per acre may be required for very dense stands of grass with 4 leaves or more. In an experiment at Stuttgart, Ark., with boom-nozzle aerial applications, propanil at 3 pounds per acre in 5 gallons per acre of herbicide-water solution was less effective on grass weeds than a similar rate in 10 gallons per acre. In another field study at Stuttgart, propanil at 3 to 4 pounds per acre applied by boom-nozzle aerial equipment in 5 to 10 gallons per acre of spray solution controlled barnyardgrass and did not injure rice. Spray drift was less with 10 than with 5 gallons.

SOIL TYPE.—Propanil applied to rice grown on the major rice soils, including silt loam and clays, controls grass weeds satisfactorily (table 10). Soil type, apparently, does not change the effectiveness of propanil on grass weeds, probably because of the postemergence action of propanil on grass plants.

TABLE 10.—*Effect of soil type on propanil activity, Arkansas, 1960-61*

[Propanil applied when weed grasses had 2 or 3 leaves]

Soil type	Control of barnyardgrass on treated plot[1]	Yield of rice, per acre		
		Untreated	Treated[1]	Increase for treated plot
	Percent	*Pounds*	*Pounds*	*Percent*
Crowley silt loam	82	2,610	4,670	79
Sharkey clay	82	3,490	3,850	11
Perry clay	85	2,460	3,350	36

[1] Values are averages from plots treated with 3 and 5 pounds of propanil per acre.

RICE VARIETY.—Almost all varieties of rice are tolerant to propanil. In field investigations, Bluebonnet 50, Caloro, Century Patna 231, Gulfrose, Nato, Northrose, and Zenith—all in the 2- to 3-leaf stages—were uninjured by 3 to 6 pounds per acre of propanil (table 11). At equivalent stages of growth, Belle Patna and Texas Patna 49 varieties were also uninjured by 3 to 6 pounds per acre of propanil. Commercial varieties in all ricegrowing areas were not injured by postemergence applications of propanil in 1961-63.

WEATHER CONDITIONS.—Grass and broadleaf weeds respond best to propanil when temperatures are moderate, or when daily maximum temperatures range from 70° to 90° F. Low temperatures during the week before spraying often slow weed growth and retard propanil activity. If daily minimum temperatures are below 50° for a few days just before treatment, propanil activity is retarded. In addition, if daily maximum temperatures do not exceed 70°, propanil activity may be reduced. For maximum effectiveness on grass weeds propanil should not be sprayed when temperatures are extremely low.

Extremely high temperatures enhance the activity of propanil on rice; thus, selectivity is

TABLE 11.—*Effect of early postemergence applications of propanil at 3 to 6 pounds per acre on yield of several varieties of rice, Stuttgart, Ark., 1960-61*

Variety	Yield of rice[1]		
	1960[2]	1961[2]	Average[2]
	Percent	*Percent*	*Percent*
Bluebonnet 50	98	98	98
Caloro	95	101	98
Century Patna 231	100	102	101
Gulfrose	92	95	94
Nato	100	105	102
Northrose	99	103	101
Zenith	93	101	97

[1] Yield expressed as percentage of the untreated weed-free check for each year and variety.
[2] No significant differences among varieties.

reduced. Propanil at 3 to 4 pounds per acre injured rice severely where daily maximum temperatures were above 95° F. for several days before spraying, especially where rice plants were under drought stress. In addition, extremely high temperatures may retard the rate of weed growth, which increases their tolerance to propanil. For maximum safety to rice and for optimum effectiveness on weeds, propanil should not be sprayed when temperatures are extremely high (95° or above).

A period of 8 to 12 hours without rain is required after treatment for effective control of grass weeds with propanil. Rain occurring soon after treatment may wash off the propanil and reduce its activity on grass weeds. Spraying, therefore, should be delayed until the threat of rain has passed.

EFFECT OF INSECTICIDES.—Propanil and insecticides, such as carbaryl, methyl and ethyl parathion, and toxaphene, applied to rice within 14 days of each other may kill rice plants and reduce stands. Rice has been burned and killed where the interval was 7 to 9 days. Rice may be damaged when insecticides are applied either before or after an application of propanil. Carbamate and phosphate insecticides consistently burn and kill rice plants when applied during a period of 14 days before or 14 days after a propanil treatment. Chlorinated hydrocarbon insecticides, such as endrin, dieldrin, aldrin, heptachlor, and DDT, cause less phytotoxicity on rice than other insecticides, but considerable yellowing and burning of the rice foliage may result. These chlorinated hydrocarbon insecticides may be safely applied 7 days before or 7 days after a propanil treatment. Rice that has been treated with aldrin as a seed treatment may be safely sprayed with propanil.

Controlling Grass Weeds With CIPC

MODE OF ACTION.—CIPC is a selective preemergence and postemergence grass-weed killer. It is usually applied immediately after emergence of grass weeds in ricefields. CIPC strongly inhibits growth of germinated seedlings of most grass plants. It is usually absorbed by the roots of grass plants, but it may give some postemergence contact kill of young weeds as foliage sprays. Rice also will absorb CIPC through its roots and may be killed. Selectivity, therefore, is obtained by placing the rice seed so that the rice roots grow in untreated soil below the treated surface. Grass weeds that emerge near the soil surface, however, have roots located in the treated soil; the roots absorb the herbicide, and weeds are killed. Selectivity is also obtained because the roots of grass weeds tend to develop near the soil surface whereas rice roots develop from nodes deeper in the soil. CIPC also kills grass-weed seedlings that may germinate or emerge after spraying. CIPC usually gives residual control of grass weeds for about 1 week after spraying, provided soil moisture is ample.

CIPC-treated plants develop a thick, short coleoptile. Initial symptoms of CIPC injury include a dark, blue-green color followed by a yellow-brown color as the plant nears death. CIPC affects cell division, cell elongation, and certain physiological and metabolic processes, such as respiration, enzyme systems, and carbohydrate metabolism.

FORMULATIONS AND RATE.—Emulsifiable and granular formulations of CIPC were compared in experiments in Arkansas where a 5-percent granular (Attaclay, RVM, 24-48 mesh) formulation of CIPC was broadcast by hand at 5 to 7 pounds of actual CIPC per acre and an emulsifiable formulation was sprayed at 6 pounds per acre. The treatments were made when the rice had 2 leaves and the barnyardgrass had 1 to 3 leaves. Rainfall soon after application washed the granules into the low areas of the plots; this resulted in a low rate in the high areas and a high rate in the low areas. Uneven distribution of the granular CIPC caused somewhat uneven control of barnyardgrass. The granular formulation controlled 50 to 60 percent of the barnyardgrass, and the emulsifiable formulation controlled 60 to 70 percent of the barnyardgrass. Since the seedlings of barnyardgrass were rather large at time of treatment, some were killed; others were inhibited severely, which reduced their competitiveness with rice. Plots treated with granular and emulsifiable formulations yielded an average of 4,640 and 4,590 pounds of rough rice per acre, respectively, as compared with 3,500 pounds for the untreated plots. Both formulations, therefore, were effective in reducing barnyardgrass competition with rice. For commercial field applications the emulsifiable formulation is generally more effective and practical than granules. This is because the emulsifiable formulation kills emerged barnyardgrass seedlings by contact, and it is not moved by irrigation water.

The effect of CIPC applied at different rates was studied over a 5-year period in Arkansas (table 12). Generally, as the rate of CIPC was

TABLE 12.—*Effect of rate of application of CIPC on control of barnyardgrass and yield of rice, Stuttgart, Ark., 1956-60*

[CIPC applied when barnyardgrass had 1 leaf. All plots were irrigated (flushed) a few days after treatment]

Rate per acre	Control of barnyardgrass						Yield of rice, per acre					
	1956	1957	1958	1959	1960	Average	1956	1957	1958	1959	1960	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Untreated check	0	0	0	0	0	0	1,660	2,510	2,270	590	390	1,480
2 pounds	------	------	------	43	70	56	------	------	------	2,660	4,620	3,640
4 pounds	73	72	30	83	80	68	4,200	4,100	3,450	4,510	4,310	4,110
6 pounds	70	82	58	88	85	77	3,810	4,340	3,830	4,550	5,140	4,330
8 pounds	83	93	62	------	------	79	3,570	4,500	4,000	------	------	4,030
10 pounds	------	98	75	------	------	86	------	4,510	4,460	------	------	4,490
L.S.D. at 5-percent level	------	7	8	13	20	12	500	260	360	750	1,030	580

increased, barnyardgrass was controlled more effectively. In 1956 and 1957 all rates controlled 70 percent or more of the barnyardgrass. In 1958 CIPC at 4 pounds per acre did not control barnyardgrass satisfactorily, but at 6, 8, and 10 pounds control was satisfactory. In 1959 CIPC at 2 pounds per acre controlled only 43 percent of the barnyardgrass, but in 1960 this rate controlled 70 percent. In 1960 the temperature was unseasonably cool after treatment, which increased the activity of CIPC. CIPC at 4 and 6 pounds in 1959 and 1960 controlled more than 80 percent of the barnyardgrass.

Yields of rice may be greatly increased by controlling grass with CIPC on areas where infestations of barnyardgrass are heavy (table 12). CIPC at 6 and 8 pounds per acre usually controlled sufficient barnyardgrass to permit the production of nearly maximum yields of rice (fig. 3). CIPC at rates lower than 6 pounds did not control barnyardgrass during most years, and at rates higher than 8 pounds returns did not justify the increased rate even if the higher rate did not injure the rice.

TIME OF APPLICATION.—Rice and barnyardgrass were treated in experiments in Arkansas with CIPC at the stages of growth indicated

FIGURE 3.—Control of barnyardgrass in rice with CIPC: *Left*, Plots sprayed early postemergence with CIPC at 6 pounds per acre; *right*, unsprayed.

in table 13. On both the Crowley silt loam and Sharkey clay, barnyardgrass was controlled best by applying CIPC at complete emergence of rice when the grass had 1 to 2 leaves and was ½ to 2 inches tall (table 13 and fig. 2). CIPC applied immediately after seeding inhibited growth of rice seedlings and reduced stands of rice when rainfall occurred soon after treatment. CIPC applied to rice at emergence caused slight burning or chlorosis along the

TABLE 13.—*Effect of time of application of CIPC on control of barnyardgrass and yield of rice, Stuttgart, Ark., 1956-60*

[CIPC applied at 4 to 8 pounds per acre]

Stage of rice at time of treatment	Stage and height of barnyardgrass at time of treatment	Control of barnyardgrass				Yield of rice, per acre			
		1956[1]	1956[2]	1959[1]	1960[1]	1956[1]	1956[2]	1959[1]	1960[1]
		Percent	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Untreated check	Untreated check	0	0	0	0	1,660	1,930	1,200	2,640
Preemergence	Preemergence	66	4	—	38	3,510	2,030	—	3,570
Just before emergence	Coleoptile	68	—	—	—	3,720	—	—	—
Emergence of 20-30 percent.	1-leaf, ½-1 inch	70	—	—	—	3,680	—	—	—
Complete emergence	1- and 2-leaf, ½-2 inches.	75	54	72	76	3,860	3,560	3,910	4,690
Postemergence:									
1 week	3- to 5-leaf, 2-4 inches	—	—	12	61	—	—	2,300	4,140
2 weeks	Tillering, 4-6 inches	—	—	0	—	—	—	860	—
L.S.D. at 5-percent level.	—	(3)	—	11	8	(3)	—	680	330

[1] Experiment located on Crowley silt loam.
[2] Experiment located on Sharkey clay.
[3] No significant differences among treatments excluding the untreated check.

margins and tips of the leaves. The rice seedlings, however, outgrew this injury soon after treatment.

Time of applying CIPC is very critical if maximum control of barnyardgrass is to be obtained. Additionally, the comparative times of emergence of rice and barnyardgrass vary with temperature, soil moisture, soil type, and possibly other factors. For these reasons, CIPC applications should be based on the growth stage of barnyardgrass rather than on that of the rice. For example, if soil moisture is adequate and the soil temperature is cool immediately after seeding, barnyardgrass may emerge before the rice, especially on clay soil. If spray applications are made on the basis of the stage of barnyardgrass, satisfactory control may be obtained by treating immediately after emergence of the first barnyardgrass. Rice may range from preemergence to complete emergence at this time.

Another advantage of applying CIPC according to the stage of growth of barnyardgrass is that the seriousness of the infestation can be determined before treatment. The need for control can actually be determined before applying CIPC, which prevents using it unnecessarily on fields or parts of fields that are not grassy.

METHOD AND DEPTH OF SEEDING.—In experiments in Arkansas, rice was seeded at three depths and CIPC was applied at two rates immediately after the rice emerged (table 14). All plots were kept free of weeds by hand weeding and water management. The plots were irrigated after treatment to keep the soil moist, which should have allowed maximum downward movement of CIPC in the soil. Both rates of CIPC affected the stand of rice less as the seeds were placed deeper in the soil. In 1958 yields were reduced only on plots seeded ½ inch deep and sprayed with CIPC at 12 pounds per acre, but in 1959 yields were reduced on plots seeded ½ inch deep and sprayed at both rates. Yield of rice seeded 1 and 2 inches deep was not reduced at either rate of CIPC.

Rice has little tolerance to CIPC when roots contact the herbicide. Rice must be seeded 1 to 2 inches deep in the soil to be protected from injury. Barnyardgrass plants that come from seed located in the upper inch layer of soil contact the herbicides and are killed. The deeper seeded rice is not injured because roots

TABLE 14.—*Effect of depth of seeding of rice and rate of application of CIPC as an early post-emergence treatment on stand and yield of rice, Stuttgart, Ark., 1958-59*

Depth of seeding rice and rate of CIPC per acre	Stand of rice[1]			Yield of rice[1]		
	1958	1959	Average	1958	1959	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
½ inch:						
6 pounds	8	11	10	108	53	86
12 pounds	2	10	6	61	56	58
1 inch:						
6 pounds	38			116		
12 pounds	20			113		
2 inches:						
6 pounds	86	85	86	107	114	110
12 pounds	63	64	64	108	123	116

[1] Stand and yield of rice expressed as percentage of untreated weed-free check. Stands in 1958 and 1959 on the untreated check were 35 and 17 plants per square foot, respectively; yields were 4,160 and 4,550 pounds per acre of rough rice, respectively.

do not contact the herbicide. Weeds that germinate and emerge from depths greater than 2 inches are normally not controlled.

When weeds are to be controlled in rice with CIPC, the crop should be drill seeded to a uniform depth of 2 inches. The seed may be broadcast, but it should be incorporated uniformly in the upper 2 inches of soil and the rate of seeding should be increased about one-third to compensate for seed located in the top inch of soil. Rice plants that come from seed located in the top inch of soil may be injured severely or even killed. CIPC cannot be used safely on rice seeded in water because most of the roots are located at or near the surface of the soil.

DOWNWARD MOVEMENT AND PERSISTENCE OF CIPC IN RICE SOILS.—The downward movement of CIPC in rice soils in Arkansas was studied in both the field and the greenhouse. In 1957 pots in the greenhouse were filled with Crowley silt loam and treated with CIPC at 6 and 12 pounds per acre. Water was applied to the soil surface at rates equivalent to ½, 1, and 2 inches of rain and in sufficient quantity to flood the soil. The soil was divided into 1-inch segments for sampling, and the cucumber bioassay was used to determine the presence of CIPC (*97*). All the CIPC was located in the top 1-inch layer of soil.

Pots in another greenhouse study in 1958 were filled with Crowley silt loam and treated with CIPC at 8 pounds per acre. Water was applied at rates equivalent to 1, 2, and 2.6 inches of rain. The 2.6-inch quantity of water inundated the soil. A chemical assay was used to determine the presence of CIPC (*35*). The 0- to ½-, ½- to 1-, and 1- to 2-inch layers of soil contained 80, 20, and 0 percent of CIPC, respectively.

The persistence of CIPC in a Crowley silt loam was studied under field conditions in Arkansas in 1958 and 1959. In 1958 CIPC at 0, 4, 8, 12, and 16 pounds per acre was applied broadcast to the soil. Samples were analyzed at weekly intervals after treatment by using both the cucumber and chemical assay methods. Both assay methods indicated that CIPC was gone from the soil in 2 weeks after treatment.

In 1959 CIPC at 0, 4, 8, and 12 pounds per acre was applied broadcast to the soil. Some plots were flooded and others remained dry with only rainfall wetting them. Samples were analyzed by the cucumber bioassay method at weekly intervals after treatment. CIPC at rates of 4, 8, and 12 pounds disappeared from the soil in 3, 4, and 5 weeks, respectively. Deactivation was as fast when the soil was flooded as when it was dry.

In summary, CIPC applied to the soil surface was localized in the top 1-inch layer of soil regardless of the quantity of water applied after treatment. CIPC applied at 4 to 12 pounds per acre deactivated in 2 to 5 weeks after its application to the soil.

WATER MANAGEMENT.—Irrigation must be applied for CIPC to be effective when no rain occurs soon after spraying. In 1957 when rainfall wet the soil, irrigation soon after treatment did not increase the activity of CIPC (table 15). In 1958 when no rain occurred during the 10 days after treatment, irrigation increased the activity of CIPC. Flooding soon after spraying usually controlled barnyardgrass better than irrigation, but it injured rice more.

CIPC controlled barnyardgrass better in 1960 when plots were irrigated 1 day after treatment than when they were flooded 8 days after treatment (table 15). The field under the latter treatment was kept flooded for 8 days, drained, and let dry for 12 days during which time barnyardgrass germinated and emerged. Emergence of new barnyardgrass plants and reinfestation of the field was prevented by keeping rice flooded after treatment with CIPC.

In summary, ample soil moisture was necessary for effectively controlling weeds in rice with CIPC. If the soil surface became dry or sunbaked, irrigation was required to control barnyardgrass with CIPC. Several irrigations may be necessary to keep the soil moist for 10 to 14 days after treatment. To prevent reinfestation with barnyardgrass, the soil must be flooded before CIPC disappears, which is usually about 2 to 5 weeks after treatment.

TABLE 15.—*Effect of water management after CIPC applications on control of barnyardgrass and yield of rice, Stuttgart, Ark., 1957-60*

[Rice and barnyardgrass had 1 leaf at time of spraying. CIPC applied at 2 to 10 pounds per acre]

Year and water management[1]	Control of barnyardgrass	Yield of rice, per acre
	Percent	*Pounds*
1957:		
Irrigated 1 day after spraying[2]	86	4,020
Irrigated 6 days after spraying[2]	87	3,940
Flooded 14 days after spraying	92	4,030
Flooded 20 days after spraying	81	3,990
L.S.D.	[3]	[3]
1958:		
Irrigated 2 days after spraying[4]	56	3,600
Flooded 2 days after spraying	85	4,050
Flooded 12 days after spraying	61	3,790
Flooded 21 days after spraying	23	2,940
L.S.D. at 5-percent level	6	470
L.S.D. at 1-percent level	9	670
1959:		
Irrigated 2 days after spraying[5]	72	3,910
Flooded 2 days after spraying	86	3,620
L.S.D. at 5-percent level	11	[3]
1960:		
Irrigated 1 day after spraying[6]	78	4,690
Flooded 8 days after spraying	48	3,340
L.S.D. at 5-percent level	17	1,030

[1] Irrigated means flooding the soil and draining it as soon as it is saturated.
[2] Flooded 14 days after treatment.
[3] No significant difference.
[4] Flooded 23 days after treatment.
[5] Flooded 20 days after treatment.
[6] Flooded 15 days after treatment.

Irrigation water applied soon after treatment did not increase CIPC injury to rice, provided it was seeded deeper than 1 inch. Even if rice is seeded 1 inch deep, seedling growth is inhibited and stands are reduced by CIPC if a flood is applied to the field 1 to 7 days after treatment. Usually rice may be flooded 10 days after spraying CIPC without injury.

SPRAY VOLUME.—Rice was sprayed with CIPC at 6, 8, 10, and 12 pounds per acre as an early postemergence treatment in 1958 and 1959 in water-spray volumes of 5, 10, 20, and 40 gallons per acre. These treatments were made with ground equipment. Barnyardgrass had 1 and 2 leaves. In 1958 CIPC applied in 40 gallons per acre controlled barnyardgrass better than applications in 5 and 10 gallons, but in 1959 there was little difference among volumes (table 16). Yields were generally greatest on plots where barnyardgrass was controlled best.

The results of experiments and general field observations indicate that, if spray coverage is uniform, CIPC may be applied with ground or aerial equipment early postemergence in a water-spray volume of 5 to 40 gallons per acre with satisfactory control of barnyardgrass and with little injury to rice. Spray volumes of less than 10 gallons per acre tend to produce spray droplets that drift excessively. Spray volumes of less than 10 gallons per acre should be avoided with ground and aerial equipment.

TABLE 16.—*Effect of volume of CIPC spray on control of barnyardgrass and yield of rice, Stuttgart, Ark., 1958-59*

[CIPC applied at early postemergence. Values are averages from plots treated with 6, 8, 10, and 12 pounds per acre]

Volume of spray per acre	Control of barnyardgrass			Yield of rice, per acre		
	1958	1959	Average	1958	1959	Average
	Percent	*Percent*	*Percent*	*Pounds*	*Pounds*	*Pounds*
5 gallons	44	68	56	2,300	4,150	3,220
10 gallons	42	62	52	2,330	4,140	3,240
20 gallons	48	75	62	2,590	4,110	3,350
40 gallons	54	65	60	2,800	4,100	3,450
L.S.D. at 5-percent level	8	(1)		340	(1)	

1 No significant difference.

SOIL TYPE.—Control of barnyardgrass with CIPC was compared on Crowley silt loam and Sharkey clay (table 17). CIPC generally controlled barnyardgrass more effectively on Crowley silt loam than on Sharkey clay, and rice yields were greater. These data and other research suggest that higher rates of CIPC are required on clay than on loam soils for equivalent weed control. Even though yield differences between untreated and treated plots were less on Sharkey clay than on Crowley silt loam, treated plots yielded much more than untreated ones on both soil types.

RICE VARIETY.—In a greenhouse experiment in Arkansas, when Arkrose, Bluebonnet 50, Century Patna 231, Cody, Nato, Toro, and Zenith were seeded 1½ to 2 inches deep, they were not injured by CIPC applied early post-

TABLE 17.—*Effect of soil type on CIPC activity in control of barnyardgrass and on yield of rice, Stuttgart, Ark., 1956-57*

[CIPC applied at early postemergence]

Year and soil type	Control of barnyardgrass on treated plot	Yield of rice, per acre		
		Untreated	Treated	Increase for treated plot
	Percent	*Pounds*	*Pounds*	*Percent*
1956:[1]				
Crowley silt loam	76	1,660	3,770	128
Sharkey clay	54	1,980	3,560	80
1957:[2]				
Crowley silt loam	82	2,510	4,340	73
Sharkey clay	62	3,500	4,590	31

1 Values are averages from plots treated with 6 and 8 pounds of CIPC per acre.
2 Plots treated with 6 pounds per acre of CIPC only.

emergence. Plants from all of these varieties planted ½ inch deep were inhibited in growth by CIPC, but varieties Century Patna 231, Cody, and Nato were inhibited more than the others.

In greenhouse experiments in Louisiana, CIPC at 6 pounds per acre injured Nato rice seeded ½ to 1½ inches deep in a silt loam soil. CIPC did not injure varieties such as Bluebonnet 50, Sunbonnet, and Zenith seeded ¾ to 1½ inches deep, but it injured these varieties when seeded shallower than three-quarter inch (*8*). This difference was due to the development of the first node near the soil surface. Nato produced the first node near the soil surface at all seeding depths, but the other varieties produced the first node deeper as the seeds were placed deeper. Roots were produced at the first node. If the roots developed in the surface soil where CIPC was present, the rice was injured.

When Bluebonnet 50, Caloro, Century Patna 231, Gulfrose, Nato, and Zenith were seeded in the field 1 or 2 inches deep and sprayed early postemergence with 6 and 12 pounds per acre of CIPC, they were not injured by the herbicide. Commercially grown varieties of rice usually were not injured by CIPC if they were seeded 1 inch or deeper.

Controlling Broadleaf Weeds With Phenoxy Herbicides

Most broadleaf and aquatic weeds and many sedges that infest rice are controlled by postemergence treatments with phenoxy herbicides, but grass weeds and some sedges are not controlled. Phenoxy herbicides used for controlling broadleaf weeds in rice include 2,4–D, MCPA, 2,4,5–T, and silvex. These herbicides are applied either as amine or low-volatile ester formulations at rates of ½ to 2 pounds per acre acid equivalent. The rate depends on the weed species and stage of growth of the rice.

MODE OF ACTION.—The mode of action of phenoxy herbicides in plants has been frequently discussed (*20, 56*). Phenoxy herbicides are absorbed by both roots and leaves. They are translocated from the site of absorption to the site of action. The movement of phenoxy herbicides, therefore, may be upward into young leaves, downward into young roots, or to rapidly growing parts anywhere in the plant. Kind of plant, growth stage of the plant, rate of plant growth, temperature, humidity, soil moisture, soil-nutrient level, soil type, and possibly other conditions affect the rate of absorption and translocation of phenoxy herbicides in plants.

Phenoxy herbicides are known to affect many interacting plant processes and cause death of the plant. Effective herbicidal action involves penetration of plant membranes, absorption and accumulation by cells, translocation through tissues and by the vascular system, and finally a toxic action usually involving the living protoplasm (*20*). Experiments have shown that the herbicidal action of phenoxy herbicides may be influenced by each of these physiological and biochemical processes and that the herbicides may in turn affect the processes.

GROWTH STAGE OF RICE AND TYPE AND RATE OF HERBICIDE.—The response of rice plants to phenoxy herbicides is greatly influenced by their stage of growth. Very young rice (from emergence to 3 weeks after emergence) is injured severely or even killed by 2,4–D, 2,4,5–T, MCPA, and silvex at rates required to effectively control weeds. Growth of rice in the early-tillering, late-jointing, booting, or heading stages may be seriously inhibited. Rice in the late-tillering stage is usually uninjured by phenoxy herbicides. This "tolerant" stage usually occurs 7 to 9 weeks after emergence for early (Nato, Northrose, Nova) and midseason (Bluebonnet 50) varieties. For very early varieties (Belle Patna, Vegold), the "tolerant" stage occurs 5 to 6 weeks after emergence. Yields of rice are greatly reduced and vegetative abnormalities are produced when 2,4–D, MCPA, and other phenoxy herbicides are applied at the early-tillering, jointing, or booting stages of growth. In a 6-year investigation, 2,4–D applied at ¾ and 2 pounds per acre to rice in the early-tillering and booting stages of growth reduced rice yields 17 and 16 percent, respectively (table 18). Yields were not significantly affected when rice was treated in the late-tillering and jointing stages of growth.

Rice responds differently to postemergence applications of the phenoxy herbicides. MCPA is less toxic to rice than 2,4–D, especially when applied during the early stages of growth (*105, 106*). During the 4- to 8-week period of rice development, 2,4,5–T and silvex are less toxic to rice than 2,4–D or MCPA. Silvex and 2,4,5–T did not reduce yields when applied at early- and late-tillering and jointing stages of growth, but they did reduce yields when applied at the booting stage (table 18). All these herbicides may reduce yields severely when they are applied during the booting and heading stages. Sometimes 2,4,5–T, MCPA, and silvex affect rice yields less than 2,4–D even when they are applied during the "tolerant" stage. Generally, rice is injured most severely by 2,4–D, followed

TABLE 18.—*Effect of time of application of phenoxy herbicides on yield of rice, Stuttgart, Ark., 1955-61*

[Values are averages from plots treated with $\frac{3}{4}$ and 2 pounds of phenoxy herbicides per acre]

Herbicide and stage of rice[1]	Change in yield, per acre[2]						
	1955	1956	1957	1958	1959	1961	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
2,4-D:							
Early tillering	−13	−20	−24	−16	−4	−27	−17
Late tillering	+1	−6	+22	+5	+8	−4	+4
Jointing	−10	−9	+12	−2	−8	--	−3
Booting	−14	−18	−21	−19	−9	−17	−16
L.S.D. at 5-percent level	8	8	21	10	12	8	11
2,4,5-T:							
Early tillering	--	--	−7	+2	+7	−1	0
Late tillering	--	--	−5	+13	+4	−2	+2
Jointing	--	--	+3	+2	−4	--	0
Booting	--	--	−21	−14	−14	−29	−20
L.S.D. at 5-percent level	--	--	21	10	12	8	13
MCPA:							
Early tillering	--	--	−20	−7	--	--	−14
Late tillering	--	--	−2	−3	--	--	−2
Jointing	--	--	+1	+3	--	--	+2
Booting	--	--	−7	−19	--	--	−13
L.S.D. at 5-percent level	--	--	21	10	--	--	15
Silvex:							
Early tillering	--	--	+2	−2	+11	--	+4
Late tillering	--	--	−10	−2	+2	--	−3
Jointing	--	--	0	−2	+6	--	+1
Booting	--	--	−18	−4	−11	--	−11
L.S.D. at 5-percent level	--	--	21	10	12	--	14

[1] 2,4-D, 2,4,5-T, and MCPA formulated as amine salts. Silvex formulated as the propylene glycol butyl ether ester. Herbicides applied about 5, 8, 11, and 14 weeks after rice emergence for early-tillering, late-tillering, jointing, and booting stages, respectively.

[2] Yield expressed as percentage of reduction (−) or increase (+) as compared with untreated weed-free check. Yields for the untreated check were 3,710, 3,500, 4,430, 3,820, 4,300, and 5,700 pounds per acre for 1955-61. The 6-year average yield for the untreated check was 4,240.

by MCPA, silvex, and 2,4,5–T in decreasing order. The difference in tolerance of rice to 2,4–D and MCPA is not significant except in the early stages of growth. The difference in tolerance of rice to 2,4,5–T and silvex is not significant. However, the tolerance of rice to 2,4–D and MCPA as compared to 2,4,5–T and silvex is significant.

Phenoxy herbicides may cause vegetative malformations in rice. Rice treated with 2,4–D at the early-tillering stage grew tubular leaves and malformed panicles (fig. 4); but that treated with MCPA, 2,4,5–T, and silvex at the same stage was not damaged. All these herbicides applied at any stage may injure roots moderately to severely. The phenoxy herbicides may cause the rice plants to turn dark green soon after spraying when applied to early-tillering rice, or cause chlorosis or yellowing when applied to booting or heading rice. They may also affect changes in the leaf position from upward to outward or downward when applied to rice in the booting or heading stages.

Rice height was reduced significantly by 2,4–D applied at the early-tillering stage (table 19). It was significantly increased by 2,4,5–T and silvex applied at the jointing and booting stage and by MCPA applied at the booting stage. Silvex, 2,4,5–T, and 2,4–D applied to booting rice reduced the bushel weight (table 19).

FIGURE 4.—*Left,* Two untreated plants; *right,* rice with malformed leaves and panicles, caused by injury from 2,4-D applied at the early-tillering stage.

TABLE 19.—*Effect of time of application of phenoxy herbicides on height and bushel weight of rice, Stuttgart, Ark., 1957-59*

[Values are averages from plots treated with ¾ and 2 pounds of phenoxy herbicides per acre]

Herbicide[1]	Change in height when rice was treated at[2]—			
	Early tillering	Late tillering	Jointing	Booting
	Percent	*Percent*	*Percent*	*Percent*
2,4-D	−3	+1	+2	+2
2,4,5-T	0	+1	+5	+12
MCPA	−2	−1	+2	+5
Silvex	+2	0	+4	+10
L.S.D. at 5-percent level	3	3	3	3
	Change in bushel weight[3]			
2,4-D	0	−0.2	+1.0	−0.9
2,4,5-T	+0.6	+.4	+.2	−1.7
Silvex	+.4	+.2	0	−1.1
L.S.D. at 5-percent level	.9	.9	.9	.9

[1] 2,4-D, 2,4,5-T, and MCPA applied as the amine formulations. Silvex applied as the propylene glycol butyl ether ester.

[2] Expressed as percentage of reduction (−) or increase (+) as compared with untreated weed-free check. Values are averages of 3 years of data, 1957–1959. Average height for untreated check was 44.8 inches for 2,4-D, 2,4,5-T, and silvex comparisons and 44.4 inches for MCPA comparisons.

[3] Expressed as percentage of reduction (−) or increase (+) as compared with untreated weed-free check. Values are averages of 1 year of data, 1959. Average bushel weight for untreated check was 46.2 pounds.

Response of rice to phenoxy herbicides is affected by rate of application. Injury to rice by phenoxy herbicides applied at other than the "tolerant" late-tillering stage increased as the rate of herbicide increased from ¾ to 2 pounds per acre. A rate of 2 pounds per acre of phenoxy herbicides applied at the late-tillering stage injured rice only slightly more than three-quarter pound.

WEED RESPONSE TO PHENOXY HERBICIDES.—Weeds respond differently to 2,4–D, MCPA, 2,4,5–T, and silvex. For example, sesbania is very susceptible to 2,4–D and 2,4,5–T (fig. 5), but curly indigo is somewhat resistant to 2,4–D

FIGURE 5.—Control of sesbania with phenoxy herbicides in rice: *Left*, Unsprayed plot; *right*, plot sprayed with 2,4–D, 2,4,5–T, or silvex.

and susceptible to 2,4,5–T (table 20). Ducksalad, however, is more susceptible to 2,4–D than to 2,4,5–T (table 21). When several species of weeds varying in susceptibility to a herbicide are present in a ricefield, mixtures of phenoxy herbicides may be used effectively (table 20). Mixtures of 2,4–D and 2,4,5–T are often more effective than either herbicide used alone.

TABLE 20.—*Effect of 2,4–D and 2,4,5–T on sesbania and curly indigo, Kelso, Ark., 1960 and 1962*

Herbicide[1]	Control of—					
	Sesbania			Curly indigo		
	1960	1962	Average	1960	1962	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
2,4-D	95	98	96	25	30	28
2,4,5-T	100	95	98	75	95	85
2,4-D plus 2,4,5-T	100	------	------	100	------	------

[1] Applied postemergence as amine salts: 2,4-D and 2,4,5-T applied at 1 pound per acre; ½ pound each of 2,4-D and 2,4,5-T applied in the mixture.

TABLE 21.—*Effect of 2,4–D and 2,4,5–T at two rates on ducksalad, Stuttgart, Ark., 1958-60*

Herbicide and rate per acre[1]	Control of ducksalad			
	1958	1959	1960	Average
	Percent	*Percent*	*Percent*	*Percent*
2,4-D:				
1 pound	80	100	------	90
2 pounds	83	100	80	88
2,4,5-T:				
1 pound	13	25	------	19
2 pounds	47	75	30	51

[1] Applied postemergence as amine salts.

Weeds are usually most susceptible to phenoxy herbicides when they are young, vegetative, and growing rapidly. Because rice is generally very susceptible to phenoxy herbicides until it is in the late-tillering stage, or 7 weeks old for many varieties, weeds in rice cannot be treated until they are somewhat larger than desired for maximum effective control. Sesbania and curly indigo may range from 2 to 6 feet tall at treatment. Because the weeds are large, the rate of herbicide required to kill them must be increased. Broadleaf weeds, such as sesbania, curly indigo, and ducksalad, usually require rates of 1 to 2 pounds per acre of herbicide to kill them at this stage of growth.

In southern rice-growing areas aquatic weeds, such as ducksalad, waterhyssop, and redstem, may become a serious problem before rice reaches the "tolerant" stage. To control these weeds, 2,4,5–T or silvex can be applied safely when the rice is in the early-tillering stage, or 4 to 6 weeks old. At this stage, silvex and 2,4,5–T should not be applied at more than 1 pound per acre and 2,4–D should not be applied at all. At rates of ¼ to 1 pound per acre, 2,4,5–T and silvex usually will not control ducksalad completely. Where there is a severe infestation, a second treatment with 2,4–D at 1 pound per acre may be required when the rice reaches the "tolerant" stage of growth. In California, MCPA at ½ to ¾ pound per acre can be applied to rice 6 to 7 weeks old without injuring it. These rates control many easy-to-kill weeds, such as redstem, waterhyssop, and waterplantain.

HERBICIDE FORMULATION.—MCPA, silvex, 2,4–D, and 2,4,5–T are applied as either amine salt or low-volatile ester formulations. The amine salt and low-volatile ester formulations of 2,4–D and 2,4,5–T are very similar in their effects on rice. Sodium, potassium, and lithium salts of the phenoxy herbicides are available but are usually less effective on weeds than amine salt or ester formulations. Rice is most "tolerant" to all formulations of phenoxy herbicides during the late-tillering stage of growth. However, at "susceptible" stages of growth, esters are more toxic to rice than amine salt formulations.

Ester formulations of the phenoxy herbicides are usually more effective in controlling most weeds than amine salt formulations. Normally, lower rates are required for the ester than for the amine salt formulations. Under most growing conditions, about ½ pound per acre of ester formulation is equivalent to 1 pound of amine salt (on an acid-equivalent basis).

Amine salts of 2,4–D and 2,4,5–T formulated as water-in-oil or invert emulsions are being developed for controlling broadleaf and sedge weeds in rice. These formulations are more active on weeds and drift less than regular amine formulations (*71*). Special equipment, however, is required for their application to ricefields. Separate tanks, pumps, and booms are used for the oil (herbicide concentrate) and water phases of the spray solution. Mixing and dispersing of the spray material take place in a specially designed nozzle where the oil and water phases converge. The herbicide concentrate contains agents that promote a "flash inversion" process when mixed with water. This process can be defined as an instant structure-producing arrangement of oil and water particles. The resulting spray solution is a highly viscous emulsion having a consistency similar to mayonnaise.

In experiments in Texas (*71*), invert emulsions sprayed with aerial equipment had only one-tenth percent of the spray volume composed of droplets smaller than 200 microns. In comparison, regular, or oil-in-water, emulsions had 30 percent of the spray volume composed of droplets smaller than 200 microns. In other experiments in Texas, invert emulsions sprayed with aerial equipment had less than 1 percent of the spray volume deposited beyond 100 feet downwind from the treated area compared with 18 percent for regular emulsion sprays.

In experiments in Arkansas, invert emulsions of 2,4–D and 2,4,5–T at ½ to 1 pound per acre applied by aerial equipment controlled weeds effectively without damaging rice seriously. Complete spray coverage was essential for control of ricefield weeds, such as ducksalad, redstem, waterhyssop, sesbania, and curly indigo. A herbicide-water spray volume of 4 to 8 gallons per acre gave uniform coverage of weeds and minimum drift of spray droplets. Spray droplets of invert emulsions should be small enough to completely cover the weeds but large enough to resist drift. Droplets that range from 200 to 1,000 microns in diameter generally meet these requirements. Invert emulsion formulations of 2,4–D and 2,4,5–T at ½ to 1 pound per acre caused brown spots on the rice leaves everywhere the spray droplets adhered to the leaf. The rice, however, outgrew the damage within 1 to 2 weeks after the spray treatment.

Granular formulations of 2,4–D and other phenoxy herbicides do not control ricefield weeds satisfactorily.

RICE VARIETY.—Commercially grown varieties of rice, such as Arkrose, Belle Patna, Bluebonnet 50, Caloro, Century Patna 231, Improved Bluebonnet, Nato, Nova, Vegold, and Zenith, respond similarly to phenoxy herbicides provided they are treated at comparable rates of application and stages of development. All these varieties are most "tolerant" to phenoxy herbicides during the late-tillering stage. The time required for rice to reach the late-tillering stage varies with variety, time of seeding, soil moisture, soil and atmosphere temperatures, latitude, light intensity, day length, and soil fertility. Early and midseason varieties reach the late-tillering stage about 7 to 9 weeks after emergence, at which time they may be sprayed safely with phenoxy herbicides. Very early-maturing varieties, such as Belle Patna and Vegold, reach the late-tillering stage 5 to 6 weeks after seedling emergence, and they should be sprayed at this time. Midseason varieties, such as Arkrose and Bluebonnet 50, remain in the late-tillering stage longer than early varieties, such as Century Patna 231 and Nato. Midseason varieties, therefore, may be sprayed over a longer period than early varieties. For example, Nato may be sprayed safely during a 2-week period, 7 to 9 weeks after emergence but Bluebonnet 50 may be sprayed during a 3-week period, 7 to 10 weeks after emergence. Seasonal environment and time of seeding affect the length of the "tolerant" spraying period.

METHOD OF SEEDING AND WATER MANAGEMENT.—When phenoxy herbicides are applied at ½ to 1½ pounds per acre during the "tolerant" stage, method of seeding and water management do not usually influence the response of rice to these herbicides. Seeding method and water management may significantly affect the activity of phenoxy herbicides on rice when the herbicides are applied in the "susceptible" stages, especially rice 3 to 6 weeks old. The stage of rice development at the time of applying phenoxy herbicides, however, is much more important than seeding method or water management.

Water management may affect the response of weeds to phenoxy herbicides. If water covers low-growing aquatic weeds, such as ducksalad, redstem, and waterhyssop, at spraying time, the weeds may not be controlled because the herbicide does not contact the plants. If weeds are not growing rapidly because of dry soil or other reasons, they may not be controlled satisfactorily. Dry soil may be caused by draining the water from the field 7 to 14 days in advance of spraying. The water should be drained from the field only a few days before spraying (3 to 6 days) to insure enough soil moisture. Flooding the field too soon after spraying may wash off the phenoxy herbicide from the weed plants and reduce its activity. Flooding may begin 12 hours after spraying, however, without affecting this activity.

FERTILIZER MANAGEMENT.—Sometimes nitrogen applied to rice before phenoxy herbicide treatment increases the activity of 2,4–D on rice. However, in field experiments in 1958 and 1960 in Arkansas, nitrogen applied to rice 14 days before or after 2,4–D treatment did not affect the activity of 2,4–D on rice. And in experiments in 1961 and 1962, the interacting effects of nitrogen and 2,4–D—the nitrogen was applied 14 days before 2,4–D treatment—reduced yields 11 and 9 percent, respectively. Yields from weed-free untreated check plots were 4,610 and 6,110 pounds per acre for 1961 and 1962, respectively. Nitrogen stimulated growth of rice 4 to 5 days after application. By the time 2,4–D was applied 14 days after the nitrogen application, rice was green and growing rapidly. After treatment with 2,4–D, rice exhibited symptoms of injury on the leaves. Rice treated with nitrogen 5 days before treatment with 2,4–D was not injured. This information suggests that nitrogen should be applied so as not to stimulate rapid rice growth just before phenoxy herbicide applications.

Nitrogen also stimulates the growth of weeds. Rapidly growing weeds are more susceptible to phenoxy herbicides than are slowly growing weeds. Nitrogen, therefore, applied before phenoxy herbicide treatment may increase the activity of these herbicides on weeds. Because nitrogen applied too far ahead of phenoxy herbicide treatments may increase their activity on rice, nitrogen should be applied 1 to 5 days before or after phenoxy herbicides even though the weeds may be less susceptible to the herbicides. If soil moisture is adequate, the weeds are usually growing rapidly enough to respond to phenoxy herbicides.

WEATHER.—Rice treated under greenhouse conditions with 2,4–D, MCPA, and 2,4,5–T was injured more when subjected for 3 days (2 days before and 1 day after herbicide treatment) to 97° F. than when subjected to 62° to 72° (*52*). Rice 2 to 8 weeks old exposed to a temperature of 97° was injured severely by phenoxy herbicides, but as the age of rice increased from 2 weeks, injury was less. Under high temperatures, rice was injured most by 2,4–D, followed by MCPA and 2,4,5–T in decreasing order.

The effect of temperature in increasing the activity of phenoxy herbicides on rice is greatly influenced by the rate of plant growth within stages of growth of rice. The stage of development and rate of growth of the rice plant at time of treatment is as important as, or more important than, temperature per se before, at, or after treatment.

Weeds respond best to phenoxy herbicides when temperatures are moderate (from 70° to 85° F.). Low temperatures (50° to 65°) during the week before spraying often slow weed growth and reduce herbicidal activity.

Rainfall immediately after postemergence foliage application of phenoxy herbicides may reduce their effectiveness on weeds. If rain occurs 6 to 12 hours after treatment, the effectiveness of the phenoxy herbicides is usually not reduced. Esters resist washing from the plant more effectively than amine salt formulations.

Moderate or high humidity (60 to 90 percent relative humidity) increases the effectiveness of phenoxy herbicides. The humidity is usually moderate to high in ricegrowing areas. Rice is often sprayed during the early morning or late afternoon when humidity is highest. Rice is sometimes sprayed with helicopters or fixed-wing airplanes at night, when humidity is very high and the wind is not blowing more than 5 miles per hour.

SPRAY VOLUME AND METHOD.—Phenoxy herbicides are applied with low-gallonage sprayers attached to ground or aerial equipment. A volume of 5 to 15 gallons is satisfactory with ground equipment, and from 1 to 10 gallons per acre is required for aerial spraying. Regardless of method of application the spray should be applied uniformly to the field.

IMPACT OF NEW AND IMPROVED METHODS OF CHEMICAL WEED CONTROL ON RICE PRODUCTION

The development of efficient and economical methods of full-season control of broadleaf and grass weeds in rice will have a revolutionary impact on rice production (*79*). Chemical methods of weed control are already having an important impact on levee construction, the kind and thoroughness of seedbed preparation, method of seeding, water management, type of irrigation, selection of varieties, fertilizer management, pest and insect control, and rotations.

Impact on Seeding Methods and Water Management

Ricegrowers in southern rice-producing areas are switching from water seeding to dry or drill seeding of rice because effective and economical herbicides are now available to control grass weeds. The trend in Louisiana had been to water seed rice to control grass weeds. Availability of effective herbicides is changing this trend.

In California deep water is used primarily to control barnyardgrass. The use of herbicides rather than deep water to control weeds is having an important impact on water conservation and rice culture in California.

Algae are a serious problem in water-seeded rice on heavy clay soils in southern rice-producing areas. The only method of controlling algal growth is by water management or draining to desiccate, or dry out, algae. Other weeds, including barnyardgrass, germinate and emerge while the field is drained for control of algae. The development of selective herbicides to effectively control algae will eliminate the need for draining, which will therefore reduce problems with grass weeds.

Dry-planted rice may be flooded immediately after rice emergence to control young barnyardgrass or other grass weeds. When temperatures are warm (80° to 95° F.), early flooding may effectively control grass weeds; but when cool temperatures (60° to 75°) prevail, control is often ineffective. Moreover, early flooding may stimulate stem elongation and weaken young rice seedlings. Effective herbicides for controlling grass weeds should eliminate the necessity for early flooding. This practice will then permit better establishment of the rice seedlings before flooding.

Impact on Selection of Varieties

Early and midseason varieties of rice are widely used for commercial production. These varieties usually require 130 to 150 days from seeding to maturity. Most varieties of barnyardgrass produce seed 45 to 70 days after rice has been seeded. Once barnyardgrass heads, it is not nearly so competitive with rice as before it heads. If nitrogen is managed properly, rice requiring 130 to 150 days to mature may recover considerably from early grass competition after the barnyardgrass matures. Moreover, barnyardgrass is not nearly so competitive with midseason varieties as it is with very early varieties.

Very early varieties of rice, such as Belle Patna and Vegold, are available for commercial production. These varieties mature in approximately 100 days from seeding. They do not have an opportunity to recover from competition of barnyardgrass, which may mature only shortly before the rice. Very early varieties should be planted only where grass weeds are to be controlled. New, effective, and economical grass-weed herbicides will be important in the profitable production of these new very early varieties of rice.

Impact on Fertilizer Management

Many of the older rice-producing areas in the South are low in phosphate and, therefore, require supplemental applications of commercial formulations of phosphate. Where phosphate is required, it is usually applied to a crop in the rotation other than rice because phosphate applied before seeding rice stimulates growth of grass weeds, especially barnyardgrass. For example, in a rice-soybean rotation, phosphate is generally applied to the soybean crop. Conceivably, this practice may lead to a deficiency of phosphate when the young rice plants need it most. An inadequate supply of phosphate during the early vegetative stages of rice development may retard rice growth and reduce yields. Herbicides effective for controlling grass weeds will allow application of phosphate before seeding rice and result in better rice yields.

Where grass weeds infest ricefields, nitrogen applications must be delayed until the grass heads. Mature grass plants utilize less nitrogen than young vegetative ones. Nitrogen applied when grass weeds are mature, therefore, is more available to the rice than to the grass. Presently (1964) the time and amount of nitrogen applied to rice depend on whether grass weeds are absent or present. Where grass weeds are absent, nitrogen can be applied 10 to 15 days after rice emergence; but where they are present, nitrogen is applied only after the grass heads out, or 50 to 60 days after rice emergence.

Impact on Insects

In an investigation in Arkansas, rice stink bug infestations were directly related to grass-weed infestations, especially barnyardgrass (*68*). Fields free of grass weeds have very low populations of stink bugs throughout the season, including the period that rice is most susceptible to damage. Conversely, fields with heavy infestations of grass weeds develop peak populations about the time rice is most susceptible to damage. Control of grass weeds in ricefields with herbicides, therefore, results in a sharp reduction in stink bug infestations.

Rolston[4] found that seed treatment with aldrin was ineffective in controlling rice water weevils where infestations of barnyardgrass were heavy, but controlled them where barnyardgrass was controlled with herbicides. Such information suggests that rice water weevils are controlled by a seed treatment with aldrin only where barnyardgrass is absent or controlled. Treatment of rice seed with aldrin to control rice water weevils is commonly practiced by commercial rice growers.

EQUIPMENT FOR WEED CONTROL

Ground equipment (hand and tractor sprayers) and aerial equipment (fixed-wing and helicopter (figs. 6 and 7) sprayers) are used for applying herbicides to rice. Aerial equipment is used more commonly than ground equipment. Aerial equipment has an advantage over ground equipment because timely and quick applications can be made even though the soil may be too wet to support a sprayer. In addition, levees present a problem with ground equipment.

[4] Private communication from L. H. Rolston, Associate Professor of Entomology, University of Arkansas, Fayetteville, 1963.

Hand Sprayers

Several types of hand sprayers are available for use in rice; they include regular and constant-pressure knapsack sprayers. If uniform and accurate herbicide applications are required, the constant-pressure knapsack sprayer is desirable. This sprayer consists of two tanks, one for the spray solution and the other for compressed air or other compressed gases. The tanks are connected with a hose through an air pressure regulator, which keeps the gas pressure constant in the liquid tank. This system may be calibrated for applying precise rates of herbicides.

FIGURE 6.—Application of 2,4-D to rice for control oof broadleaf weeds with a fixed-wing airplane sprayer.

FIGURE 7.—Application of 2,4–D to rice for control of broadleaf weeds with a helicopter sprayer.

Tractor Sprayers

Tractor-mounted sprayers consist of a power-takeoff-driven pump, tank or tanks, solution delivery hose, pressure regulator, pressure gage, nozzles, strainers, and booms. The boom-type sprayer is most commonly used, but boomless sprayers are used sometimes, especially over rough terrain and where even distribution of spray is not essential.

Herbicides are applied to rice with ground equipment at spray volumes of 5 to 20 gallons per acre.

Pumps

Several types of pumps, including centrifugal, piston, gear, roller, and rubber impeller, are available for spraying herbicides. They are rated in gallons-per-minute discharge at specific speeds. The capacity of the pump should be about twice that of the total nozzle delivery rate to provide adequate flow through the bypass line for hydraulic agitation in the tank.

Tanks

Tanks are available in mild steel (such as oil drums), stainless steel, aluminum, and plastic reinforced with fiber glass. Much of the trouble with clogged nozzles in oil-drum tanks is caused by rust and scale that accumulate between spraying seasons. The other three materials are more expensive than mild steel, but they withstand the corrosive action of most herbicides. Nozzle stoppage is much less when tanks are constructed of corrosive-resistant materials.

Hoses and Connections

The hose should be resistant to sunlight, oil, and chemicals and should withstand general use. A hose made of base rubber combined with tough rayon and nylon cord gives good service. Hose connections should be made of corrosive-resistant materials and should have openings large enough to avoid restrictions in the lines.

Pressure Regulators

Two types of bypass pressure regulators are generally available for pressure regulation for low-volume, low-pressure spraying. One type consists of a spring over a ball and seat; the other consists of a spring, diaphragm, plunger, and seat. Both types have an adjusting screw to regulate pressure.

Sometimes a pressure-reducing regulator is used in conjunction with the bypass pressure regulator. The bypass valve may be set at 10 to 15 pounds above the desired pressure at the nozzle tips. The reducing regulator may then be set to maintain a uniform pressure on the nozzle tips even though the pump may cause some fluctuation in the delivery pressure at the bypass valve.

Pressure Gages

The pressure gage must be accurate. It should be placed in the hose between the pressure regulator and the delivery nozzles. Gages with a range of 0 to 100 pounds per square inch are satisfactory. The scale should be in 1- or 2-pound divisions to facilitate easy and accurate calibration of the sprayer.

Nozzles

Broadcast booms used for spraying rice should usually be fitted with fan-type nozzle tips that produce a heavy center spray. Size of the nozzle is determined by the particular spraying job. The manufacturer's guide may be consulted for information.

Booms

Broadcast spray booms are classed as wet or dry. A pipe or metal tube transports the liquid in the wet boom. Usually a pipe coupling or eyelet fitting is welded or placed over small holes spaced 18 to 20 inches apart in the pipe. The materials used for making the boom should be resistant to corrosion to prevent nozzle stoppage.

In the dry boom the supporting member does not carry the liquid. The liquid is transported by hoses and fittings, which consist of pipe tees bolted to the supporting frame. This type of boom is very satisfactory because corrosion is minor and the boom can be straightened after accidental bending without leakage.

Strainers

Line and nozzle-tip strainers should be used in the sprayer to remove solid particles that may clog nozzle tips. Usually 50- or 100-mesh screens are satisfactory. All strainers should be removed, cleaned, and inspected for holes every few days.

Fixed-Wing Airplane Sprayers

Most airplane sprayers are equipped with booms and nozzles that are similar to those on tractor sprayers. Other distribution systems include rotating brushes, disks, hollow propellers, and the venturi type, which may be a single large unit under the fuselage or several small units mounted under each wing. The boom-type distribution system is usually more desirable for spraying herbicides.

Phenoxy herbicides are applied to rice at spray volumes of 1 to 10 gallons per acre to control broadleaf weeds. Propanil and CIPC used to control grass weeds are applied at volumes of 10 gallons per acre.

The same type of pumps used with tractors are used with airplanes, but the centrifugal pump is most common. The pump is mounted outside the fuselage and driven by a small propeller. The size of the propeller may be changed for the desired volume of spray. The capacity of the pump should be about twice the nozzle output to allow sufficient liquid through the bypass valve for hydraulic agitation.

Tanks are usually made of corrosive-resistant materials, such as aluminum or fiber glass, and they carry 90 to 250 gallons of spray liquid.

Pressure regulators, pressure gages, hoses, and strainers used for aerial spraying are similar to those used on tractors.

Booms are usually made of corrosive-resistant materials, such as aluminum. To minimize drift of spray, the boom should be placed as far below the wing as practical, which is usually about 1 foot; and it should extend to within about 2 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.

Nozzles for fixed-wing airplane sprayers are made of corrosive-resistant material, such as aluminum, brass, or nylon. They are equipped with quick-cutoff diaphragm, screen, and jet. Spray droplet size may be greatly affected by the angle at which the nozzles discharge into the airstream. Smaller droplets occur when the nozzles are directed against, or across, the airstream than when they are directed with it. Droplet size is also affected by pump pressure and nozzle-orifice diameter. Most ricegrowing States have regulations that specify the maximum operating pressure for aerial spraying of phenoxy herbicides; this usually must not exceed 20 to 45 pounds per square inch. A compromise must be 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. Sprays usually give adequate weed control if droplets range from 50 to 300 microns in diameter.

Spray pattern or distribution is important. Proper placement and spacing of nozzles along the boom helps to distribute the spray evenly. Usually the spray pattern will be improved if more nozzles are placed on the right side of the plane than on the left. The air is swirled from right to left by the counter clockwise rotation of the propeller (facing the propeller). Spraying the proper swath width also improves spray distribution. The wing span of the airplane governs the swath width. The width of the swath should be about equal to—but should never exceed—the wing span of the plane. Proper flying height improves spray pattern and reduces spray drift. Spray distribution is best when fixed-wing airplanes fly at 10 to 15 feet, but spray drift is less when they fly at 5 to 10 feet. Phenoxy herbicides should be released at the lowest possible height, but propanil may be released at a height that gives best spray distribution.

Helicopter Sprayers

Helicopters are frequently used to apply herbicides to rice. Some users claim that spray applications from helicopters provide better coverage and control of weeds than do those from fixed-wing planes because the downwash from the helicopter motors forces the spray down into the crop. In closely bounded fields a helicopter can be used advantageously to give better weed coverage near the edge of the ricefield and to reduce spray drift to nearby susceptible crops. The helicopter may stay within the ricefield while turning at the ends of the field. This eliminates flight over nearby susceptible crops, which prevents accidentally contaminating these crops by spray trailing the aircraft or by leakage of spray.

The boom-type sprayer is used on helicopters. Pumps, tanks, hoses, pressure regulators, pressure gages, nozzles, booms, and strainers used on helicopters are similar to those used on fixed-wing planes.

A helicopter carries about 60 gallons of spray liquid in two spray tanks; one is located on each side of the aircraft for balance. The flying height is usually 2 to 5 feet above the rice. The swath width should be about equal to the length of the boom.

CALIBRATION OF TRACTOR AND AERIAL SPRAYERS

Unless the sprayer is calibrated properly, the crop may be injured by too much herbicide or the weeds may be controlled poorly by too little herbicide. The herbicide must be mixed with water in the right proportion. Proper calibration of the sprayer is very important for good results with herbicides.

Low-gallonage sprayers are used for spraying herbicides on rice. Volumes of 5 to 20 and 1 to 10 gallons per acre are used for tractor and aerial sprayers, respectively. A good method of calibration is to make initial adjustments to suit the machine and job requirements and then make a trial run to determine the actual output of the sprayer. The herbicide spray solution should then be prepared accordingly. The calibration should be repeated frequently to check for nozzle-orifice wear and other things that may change the spray output.

The nozzle (type, size, etc.) that will give the desired volume of spray per acre is first selected from the manufacturer's guide. Then all nozzles are checked to see if they are discharging evenly. Individual nozzles may be checked for accuracy of delivery by measuring the volume of spray from each nozzle in 1 minute. If serious variations exist, the faulty nozzle should be cleaned or replaced. The speed of the tractor or aircraft that best fits the spraying job requirements is then selected. There are many ways of calibrating a sprayer. One method of calibrating a tractor sprayer and one method of calibrating an aerial sprayer follow.

Tractor Sprayers

(1) Select an area for a test run that is similar to the field to be sprayed. Measure off a distance of 660 feet.

(2) Place the sprayer on level ground and fill the spray tank with water. Make sure it is full.

(3) Spray the 660-foot test run. Operate the sprayer at exactly the same pressure and tractor speed that will be used in the field—usually about 3 or 4 miles per hour.

(4) Upon reaching the 660-foot mark, stop spraying. Then measure carefully the number of quarts needed to refill the tank.

(5) Convert the number of quarts to gallons of water required to refill the spray tank by dividing by 4, and then multiply this figure by 66. Divide the results by the width, in feet, of the strip sprayed. The answer obtained is the number of gallons of spray liquid the sprayer will apply on 1 acre when it is operated at the same settings.

Example: Suppose the sprayer boom sprayed a strip 30 feet wide. After the 660-foot strip is sprayed, 10 quarts is required to refill the tank. Ten quarts divided by 4 equals 2½ gallons. Multiply 66 by 2½, which equals 165. Then divide 165 by 30 (the width in feet of the sprayed strip). The answer is 5½, which is the gallons of spray liquid applied per acre.

Aerial Sprayers

(1) Measure off a distance of 1 mile (5,280 feet).

(2) Fill the spray tank with water. Make sure it is full.

(3) When the weather is similar to that which will prevail while spraying the rice, spray the 1-mile test run. Operate the sprayer at exactly the same pressure and airplane speed (ground speed) that will be used in the field—usually about 80 to 85 miles per hour for fixed-wing planes and about 40 miles for helicopters.

(4) Upon reaching the 1-mile mark, cut off the sprayer. Measure carefully the gallons of water needed to refill the tank.

(5) Multiply the number of gallons of water needed to refill the tank by 8¼. Divide the results by the width, in feet, of the strip sprayed. The answer obtained is the gallons of spray liquid the sprayer will apply on 1 acre when it is operated at the same settings.

Example: Suppose the strip sprayed is 33 feet wide. After the 1-mile strip is sprayed, 12 gallons is required to refill the tank. Multiply 12 by 8¼, which equals 99. Then divide 99 by 33 (the width in feet of the sprayed strip). The answer is 3, which is the gallons of spray liquid applied per acre.

Slight pressure adjustments may be required to obtain the desired liquid output of the sprayer. Each time the sprayer is readjusted the output of the sprayer must be checked as described. It is a good idea to check the spray distribution pattern on both tractor and aerial sprayers. This may be done by placing a water-soluble dye in the tank. Place a strip of white paper on the ground across the swath and spray and operate the tractor or aerial sprayer exactly the same as it will be operated in the field. Slight height, nozzle, and other adjustments may be required to obtain the desired spray pattern.

Once the sprayer is calibrated accurately, determine the acres that can be sprayed with one tankful of spray liquid. This is done by dividing the capacity of the tank (in gallons) by the spray applied per acre (in gallons).

Example: Suppose the tank holds 90 gallons of spray liquid and the sprayer is calibrated to apply 3 gallons per acre. Divide 90 by 3. The answer is 30, which is the number of acres one tankful of spray liquid will cover.

Now determine the amount of commercial herbicide and water needed to make the desired spray solution. Suppose you want to kill ducksalad in rice, which requires 1½ pounds per acre of 2,4,5–T acid equivalent. Multiply 30 by 1½, which equals 45, or the pounds of 2,4,5–T required for each tankful of spray. Suppose the commercial 2,4,5–T you are using contains 4 pounds per gallon acid equivalent. Divide 45 by 4, which equals 11¼, or the gallons of 2,4,5–T needed for each tankful of spray. Thoroughly mix the 11¼ gallons of 2,4,5–T with sufficient water to fill the tank. You are now ready to spray.

WEEDS

Accurate weed identification is essential to a satisfactory weed-control program because weeds differ in their response to various chemical and cultural methods of control. Only weeds that cause major losses in rice production are described in this section. However, others not included are also known to reduce rice yields. The principal species infesting rice in the United States are listed, and a description, distribution and habitat, and information on control are included. When a weed is known by more than one common name, the most widely used names are given. Pictures of representative species are also included. The background board in most of the pictures was marked off in 6-inch squares.

Arrowhead (fig. 8)

Sagittaria spp.

OTHER NAMES.—Swamp-potato and arrowheadlily.

PRINCIPAL SPECIES.—*Sagittaria montevidensis* Cham. & Schlecht., *S. latifolia* Willd., *S. cuneata* Sheldon, and *S. graminea* Michx.

DESCRIPTION.—Species of arrowhead are perennials that reproduce by seed, underground rhizomes, and tubers. They are rooted aquatics, usually emersed. The common species have arrow-shaped leaves, but some species have linear ones. The normal leaves are all basal with petioles usually as long as the water is deep. Plants are normally 1 to 2 feet tall.

DISTRIBUTION.—Arrowheads grow in all rice-producing States, and several species grow in most States. They grow in shallow water in irrigation and drainage canals, in ricefields where stands are thin, and in ricefield bar ditches.

CONTROL.—Arrowheads may be controlled by good cultural practices, such as thorough land preparation, land leveling, and proper construction of levees. A good stand of rice discourages arrowheads.

They may also be controlled in the ricefields by 2,4–D, 2,4,5–T, silvex, or MCPA at ½ to 1½ pounds per acre. Sometimes only partial control is obtained at these rates. These herbicides should be applied to rice when it is in the "tolerant" stage (p. 24). In irrigation canals or on uncultivated areas these herbicides may be applied at 4 to 8 pounds per acre, with water or fuel oil as the carrier.

FIGURE 8.—Arrowhead (*Sagittaria montevidensis*).

Barnyardgrass

Echinochloa spp.

PRINCIPAL SPECIES, VARIETIES, AND COMMON NAMES.—*Echinochloa crusgalli* (L.) Beauv. (fig. 9) called watergrass, millet, bluestem, and baronetgrass; *E. colonum* (L.) Link called jungle-rice, little barnyardgrass, and short-millet; and *E. cruspavonis* (H.B.K.) Schult. called gulfcockspur and cattailgrass. There are many varieties of *E. crusgalli*, including *zelayensis* (H.B.K.) Hitchc., *longiseta* (Trin.) Farw., and those commonly known as baronetgrass and white barnyardgrass.

DESCRIPTION.—Species and varieties of barnyardgrass that infest rice are annuals; they reproduce by seed. Because the species differ greatly, separate descriptions are given.

Echinochloa crusgalli varies more morphologically than other species do. It is erect to decumbent and ranges from 3 to 6 feet tall at maturity. Some varieties of barnyardgrass are awnless; others have awns—the length varies with the variety. Varieties differ greatly in date of maturity, height, and size of stems, heads, and seeds. (Panicles of several varieties of *E. crusgalli* are shown in figure 10.) Varieties also differ in their ability to emerge under water. White barnyardgrass, which grows in

FIGURE 9.—Barnyardgrass (*Echinochloa crusgalli*), mature plant.

FIGURE 10.—Barnyardgrass panicles, showing head types.

California, germinates under water; but other varieties usually will not germinate when seeds are covered with water.

Echinochloa colonum is prostrate to erect and ranges from 1 to 2 feet tall at maturity. It branches more at the base than *E. crusgalli* and grows more openly and has smaller culms, heads, and seeds.

Echinochloa cruspavonis is erect or sometimes decumbent, and plants are about 3 to 4 feet tall at maturity. The panicles are very conspicuous because they are large, and the spikelets have long awns.

All species of barnyardgrass tiller abundantly and produce abundant viable seed that may persist for many years in the soil.

Young barnyardgrass plants often are difficult to distinguish from rice. The collar region on the leaves may be used to differentiate these plants. Barnyardgrass has no ligules or auricles; rice has membranous ligules and hairy auricles (fig. 11).

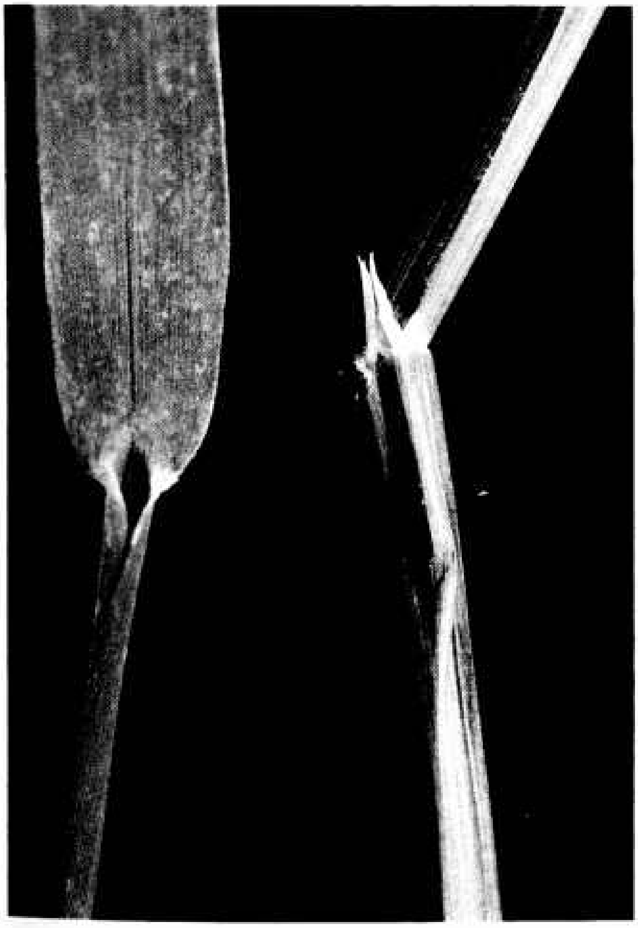

FIGURE 11.—Collar region of barnyardgrass (*left*) and of rice (*right*). Barnyardgrass has no ligule or auricle; rice has ligules and hairy auricle.

DISTRIBUTION.—*Echinochloa crusgalli* is a troublesome weed in all ricegrowing States. *E. colonum* and *E. cruspavonis* grow mostly in Louisiana and Texas, but *E. cruspavonis* is not widespread. All species grow well in rice because water is plentiful. Barnyardgrass grows in the rice crop, on levees, along irrigation and drainage canals, on reservoir banks, and in sloughs and other wet areas. It grows in row crops, such as soybeans, corn, and cotton. Seeds may be spread by irrigation water, animals, birds, crop seeds, and other carriers. Barnyardgrass greatly reduces rice yields.

CONTROL.—Water seeding, flooding young plants, rotations, good land preparation, land leveling, and herbicides help control barnyardgrass.

Most species and varieties of barnyardgrass do not germinate under water; therefore, this weed may be controlled by continuous submergence of the land or by seeding the rice in water. The land should be covered with 4 to 8 inches of water immediately before or after emergence of barnyardgrass plants.

Adequate land preparation, proper levee construction, and land leveling for maintenance of a uniform depth of water help control barnyardgrass. Delayed planting of rice controls barnyardgrass, since the land may be prepared early in the spring and disked every 2 or 3 weeks to kill grass plants as they emerge. The last cultivation should be shallow (2 to 3 inches) to prevent bringing deeply buried seed to the soil surface.

Rotations, such as row crops and rice or small grains and rice, help control barnyardgrass. It should be controlled in the row crop by cultivation or herbicides or both. Small grain crops, such as oats or wheat, rotated with rice help control barnyardgrass, because the land may be clean fallowed during the summer after the small grain has been harvested.

Barnyardgrass can be controlled either by propanil at 3 or 4 pounds per acre applied at the 1- to 3-leaf stage or CIPC at 6 to 8 pounds applied just before or immediately after emergence. See pages 12 and 18 for more details on chemical control of barnyardgrass.

Beakrush (figs. 12 and 13)

Rhynchospora corniculata (Lam.) Gray

OTHER NAMES.—Spearhead, hornedrush, umbrellaweed, tadpole-sedge, and ace-of-spades.

PRINCIPAL SPECIES.—*R. corniculata* is the only species of economic importance in rice.

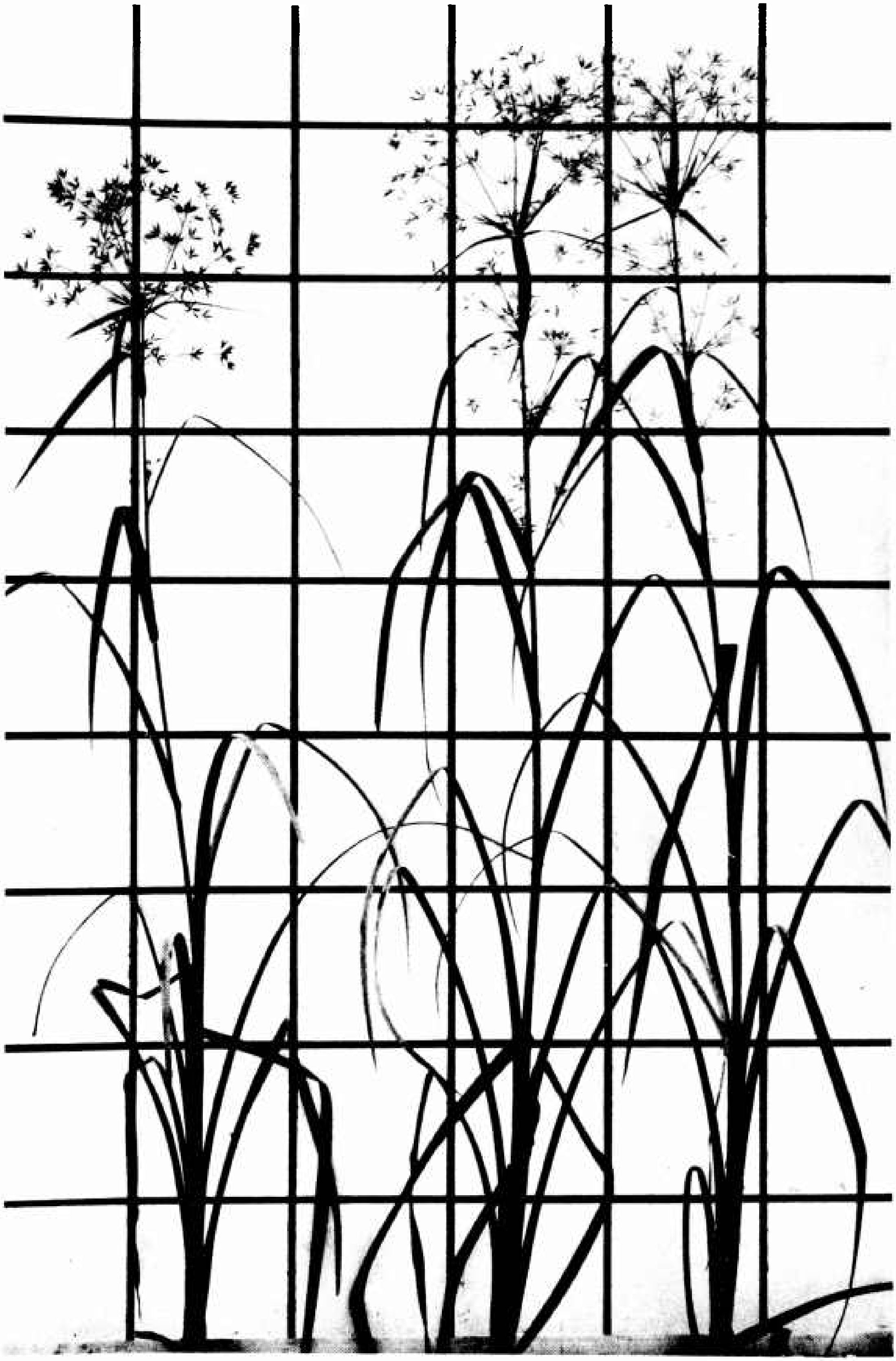

FIGURE 12.—Beakrush (*Rhynchospora corniculata*), whole plant.

DESCRIPTION.—Beakrush is a perennial that reproduces by seeds and rhizomes. Stems are stout, leafy, triangular, and from 2 to 6 feet tall. Leaf blades have a rough margin. The inflorescence is widely branched. Seeds are about 1/4 inch long, have beaks 1/2 to 3/4 inch long, and are extremely difficult to separate from the rice seed.

FIGURE 13.—Beakrush, panicle.

DISTRIBUTION.—Beakrush is a troublesome weed in the southern ricegrowing areas. It grows in ricefields, canals, ditches, and other wet areas. It competes with rice to reduce yields, interferes with harvesting and drying, and reduces quality of rice.

CONTROL.—Rotations, good seedbed preparation, cultivation, and drainage help control beakrush. Propanil at 3 to 4 pounds per acre applied to plants 3 to 4 inches tall kills beakrush.

Brachiaria (fig. 14)

Brachiaria platyphylla (Griseb.) Nash

OTHER NAME.—Signalgrass.

PRINCIPAL SPECIES.—No others.

DESCRIPTION.—Brachiaria is an annual that reproduces by seed. Young plants are similar to crabgrass seedlings, but they have shorter, wider leaves. Seeds are about twice as large as crabgrass seed. Brachiaria plants are about 1 to 2 feet tall when mature.

FIGURE 14.—Brachiaria (*Brachiaria platyphylla*).

DISTRIBUTION.—Brachiaria grows only in the southern rice area. It grows well in the rice crop, on levees, and along edges of canals. It reduces yields by competition with rice early in the growing season.

CONTROL.—Brachiaria germinates well in moist soil but not under water. Water-seeding of rice discourages brachiaria. Proper seedbed preparation, rotations, land leveling, and fallowing help control this weed. Propanil at 3 or 4 pounds per acre applied to young plants in the 1- to 3-leaf stage kills brachiaria.

Bulrush (fig. 15)

Scirpus spp.

PRINCIPAL SPECIES AND COMMON NAMES.—*Scirpus mucronatus* L. (fig. 16) called roughseed bulrush; *S. fluviatilis* (Torr.) Gray called river bulrush; and *S. acutus* Muhl. called hardstem bulrush and great bulrush.

DESCRIPTION.—Most of the bulrushes troublesome in rice and all principal species are perennial plants that reproduce by seed, rhizomes, or rootstocks. *Scirpus mucronatus* and *S. fluviatilis* have triangular, stout culms that grow 2 to 4 feet tall. *S. acutus* has round, erect culms ranging from 3 to 6 feet tall.

DISTRIBUTION.—Bulrushes are troublesome in most rice-producing States. *Scirpus mucro-*

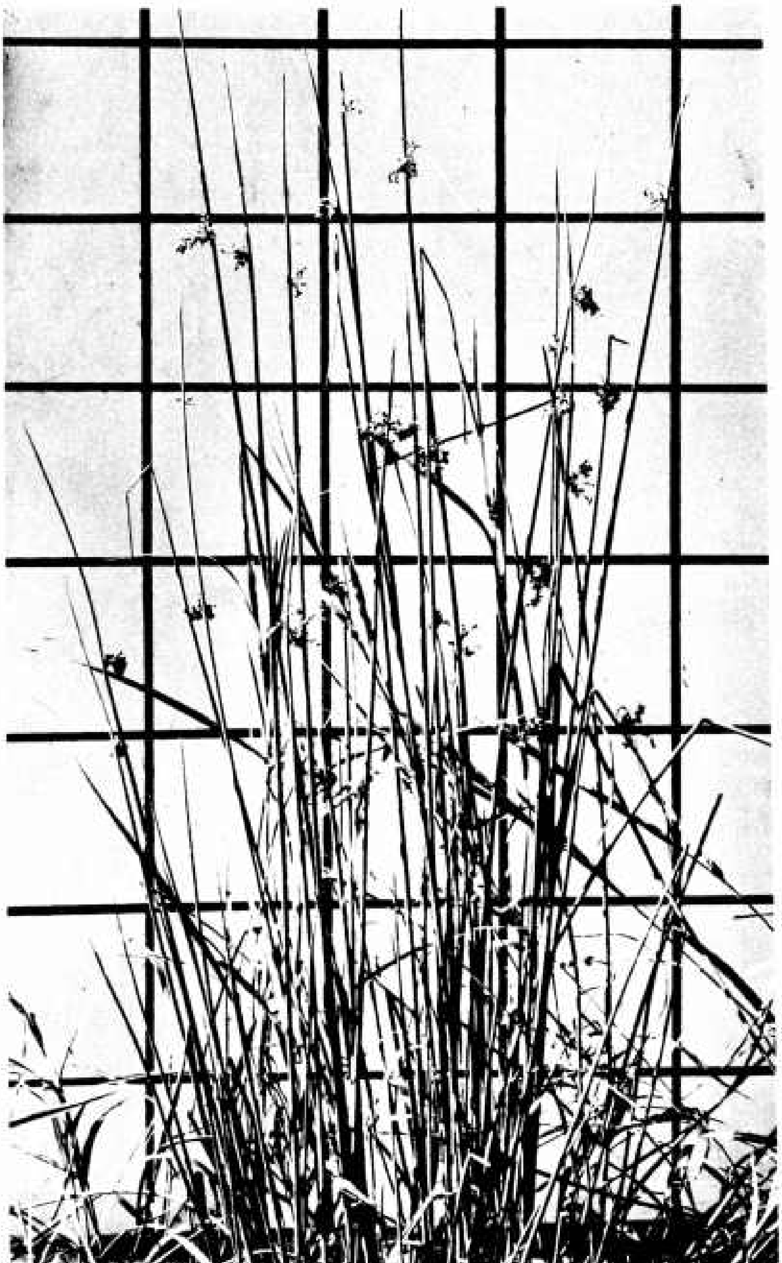

FIGURE 15.—Bulrush (*Scirpus acutus*).

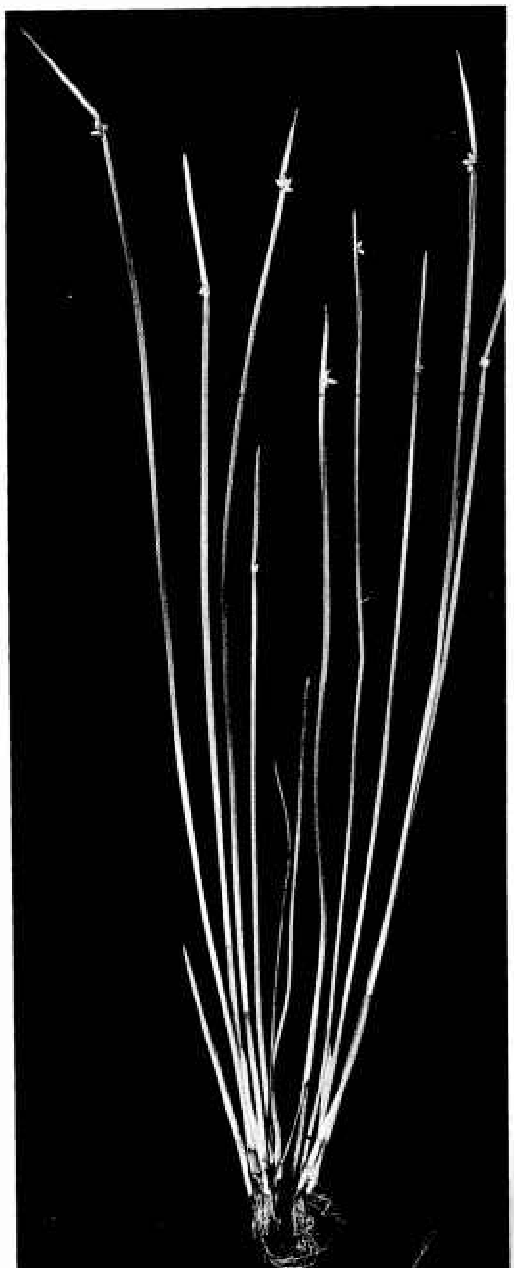

FIGURE 16.—Roughseed bulrush (*Scirpus mucronatus*).

natus and *S. fluviatilis* grow in California, but the former is more serious because it infests large acreages of rice. Bulrushes in the Southern United States may infest poorly drained ricefields, drainage and irrigation canals, ditches, reservoirs, and other wet areas. They compete with rice, lower yields, interfere with harvest, and impede flow of water in canals and ditches.

CONTROL.—*Scirpus mucronatus* is controlled in ricefields by 2,4–D or MCPA at 1 pound per acre. But most bulrushes are not controlled selectively in rice with herbicides. Cultural control methods, such as rotations, land leveling, good seedbed preparation, cultivation, and mowing, therefore, are used in the rice crop. Bulrushes infesting uncultivated areas may be killed with low-volatile esters of 2,4–D at 4 to 8 pounds per acre, dalapon at 15 to 20 pounds, or amitrole at 6 to 10 pounds. Repeated applications may be necessary. Addition of 5 to 10 gallons of diesel oil per acre to the dalapon spray solution greatly increases effectiveness. Dalapon and amitrole are safer to use near crops sensitive to 2,4–D.

Burhead (fig. 17)

Echinodorus cordifolius (L.) Griseb.

OTHER NAMES.—Mudbabies and creeping waterplantain.

PRINCIPAL SPECIES.—*E. cordifolius* is the only species of economic importance in rice.

DESCRIPTION.—Burhead is an aquatic, emersed, erect annual that reproduces by seed. Plants are 24 to 48 inches tall and bear many whorls of flowers. Leaves have long petioles; leaf blades are egg shaped, have heart-shaped

FIGURE 17.—Burhead (*Echinodorus cordifolius*). Courtesy of the University of California.

bases, and are up to 10 inches long and 5 or 6 inches wide. The seed cluster resembles a bur and is $\frac{1}{2}$ to 1 inch in diameter. Seeds are about $\frac{1}{10}$ inch long, sharply ridged, and short beaked.

DISTRIBUTION.—Burhead grows in most rice-producing States. It frequently grows in ricefields, shallow irrigation and drainage canals, ditches, potholes, sloughs, and other wet areas. It is most troublesome in areas where rice stands are thin or where cold water enters the ricefield. Burhead germinates and emerges under water.

CONTROL.—Burhead is controlled by good seedbed preparation, adequate stands of rice, drainage, and herbicides. It is very susceptible to phenoxy herbicides. MCPA and 2,4–D at $\frac{3}{4}$ to $1\frac{1}{2}$ pounds per acre give control. These herbicides should be applied when rice is in the "tolerant" stage of growth (p. 24).

Cattail (fig. 18)

Typha spp.

OTHER NAMES.—Flags, tules, and reedmace.

PRINCIPAL SPECIES.—*Typha angustifolia* L., *T. domingensis* Pers., *T. glauca* Godr., *T. latifolia* L.

DESCRIPTION.—Species of cattails are perennials that reproduce by rootstocks and by minute, airborne seeds that germinate readily in mud and occasionally in shallow, clear water. The plants are erect and have long, narrow leaves. The flowers are in a long and very dense cylindrical spike terminating the stem. There is an extensive rhizome system. Plants are 4 to 8 feet tall and usually grow in colonies. Seeds may remain viable for 5 years or more.

DISTRIBUTION.—Cattails grow in all rice-producing States, but all species are not found in each State. They grow in shallow water in irrigation and drainage ditches and may grow in the rice crop where drainage is inadequate.

CONTROL.—Cattails may be controlled by drainage and cultivation. If they are serious in low areas of ricefields, they may be controlled by drainage, summer fallowing, and cultivation. Cattails may be controlled also by cutting them close to the ground at two special stages of growth. The first cutting should be made when the heads are two-thirds of full size but not mature enough to scatter viable seed. The second cutting should be made about a month later when regrowth has attained a height of about 2 feet.

No herbicide will selectively kill cattails without injuring rice. Cattails may be controlled chemically in uncultivated areas with low-volatile esters of 2,4–D at 4 to 6 pounds per acre. Use in a 1 to 20 oil-water emulsion with a total volume of 150 to 300 gallons per acre applied as a foliage spray. The first spray treatment should be made just before heading of cattails, and the treatment will need to be

FIGURE 18.—Cattail (*Typha latifolia*).

repeated on regrowth. About three applications over a 2-year period are necessary for complete control. Dalapon at 15 to 20 pounds per acre or amitrole at 6 to 10 pounds applied in late summer after heads are firm control cattails. The addition of 5 to 10 gallons of diesel oil per acre to the dalapon spray solution greatly improves effectiveness. Repeated applications may be necessary. Dalapon and amitrole are safer to use near crops sensitive to 2,4-D.

Curly Indigo (fig. 19)

Aeschynomene virginica (L.) B.S.P.

OTHER NAMES.—Sensitive jointvetch, northern jointvetch, indigo, bashfulweed, and coffeeweed.

PRINCIPAL SPECIES.—No others.

DESCRIPTION.—Curly indigo is an erect, leguminous annual that reproduces by seed. Stems are branched, sparsely bristled at base

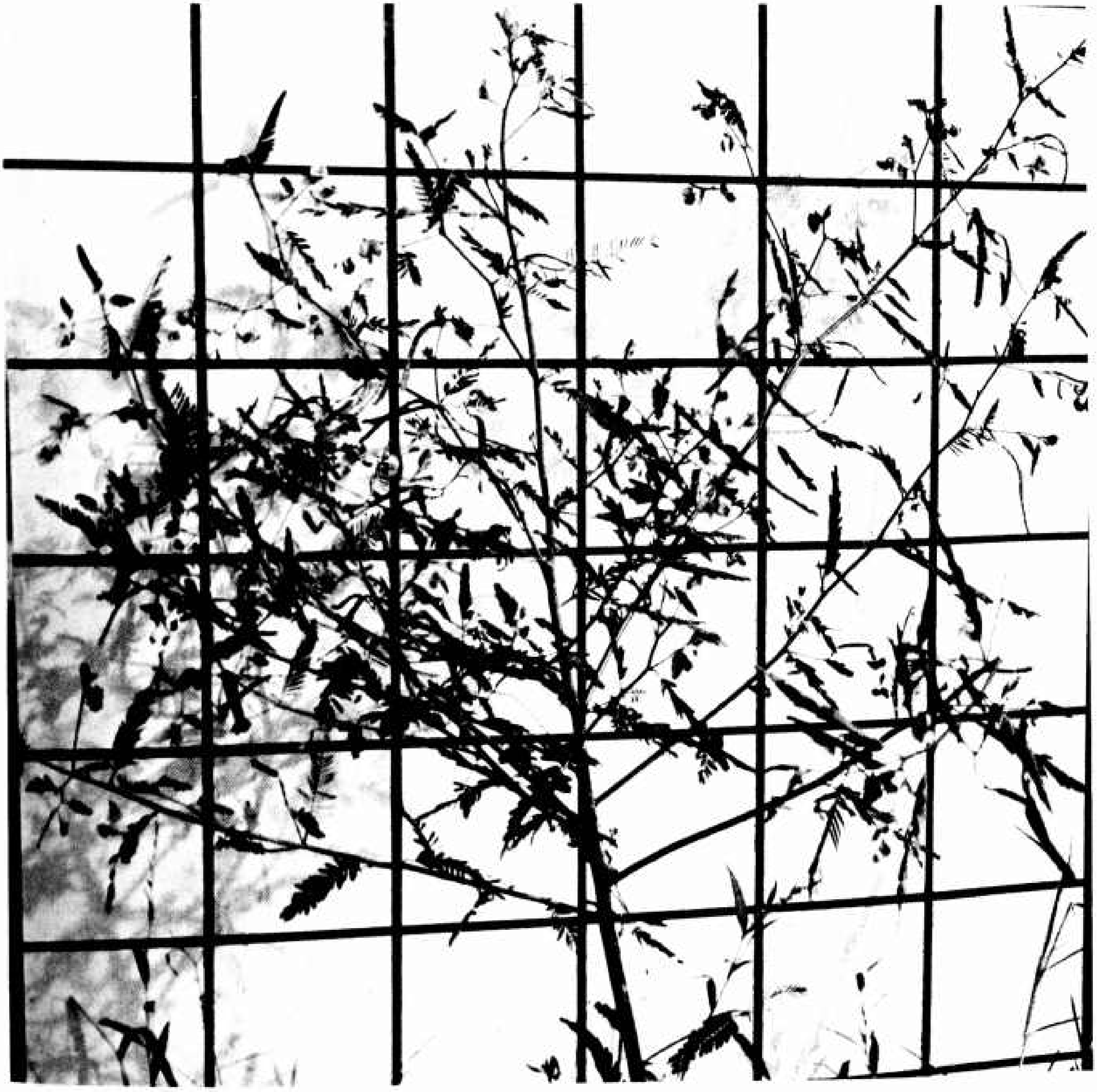

FIGURE 19.—Curly indigo (*Aeschynomene virginica*).

but abundantly bristled near apex, and 2 to 5 feet tall. Leaves are compound, are short petioled, and have 25 to 55 linear-oblong leaflets that fold when touched. Stipules are large and deciduous, especially those below the tip of the stem. Inflorescence is axillary, is often leafy, and contains 1 to 6 yellow, red-veined flowers. Pods are 1 to 3 inches long and segmented into 4 to 10 nearly square joints that separate easily at maturity. Young plants may be identified by large stipules (fig. 20) and bristly stems near the shoot apex. Seeds are kidney shaped and viable for many years in the soil.

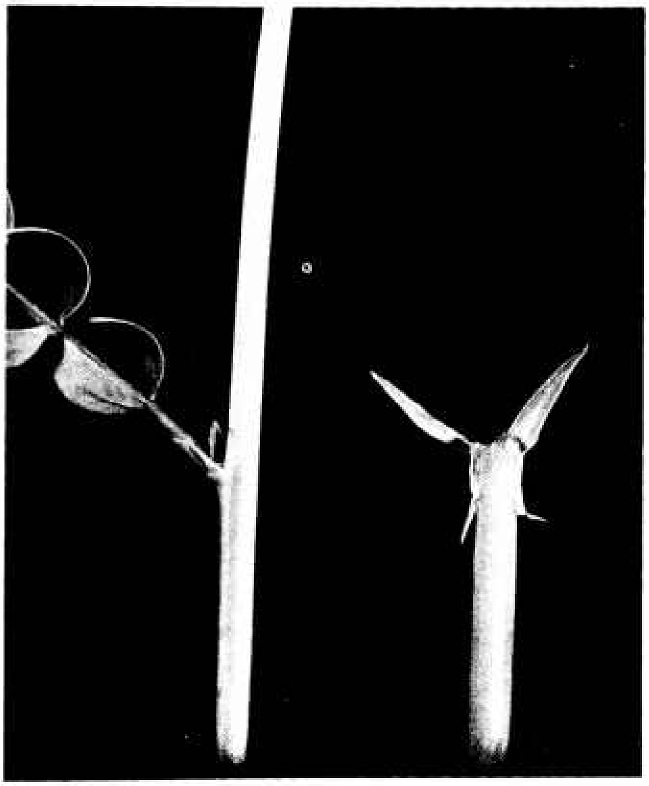

FIGURE 20.—*Left,* Sesbania, showing small narrow stipules; *right,* curly indigo, showing large stipules.

DISTRIBUTION.—Curly indigo is a serious weed in the southern rice-producing areas. It grows in the rice crop, on field levees, in uncultivated fields and waste areas, along canal and ditch banks, and in other areas. It competes with rice, interferes with harvest, and reduces quality because its seeds are difficult to remove from rough and milled rice.

CONTROL.—Curly indigo is controlled by rotations, fallowing, cultivation, good seedbed preparation, water seeding, hand pulling, and herbicides. Rotations of either row crops or pasture and rice help control this weed. It may be controlled in row crops by cultivation and in pasture by grazing and mowing. Summer fallowing with timely and thorough cultivation controls it. Water seeding controls curly indigo because seeds do not germinate when covered with water. Hand pulling is practical when only a few scatterd plants are present.

Curly indigo is susceptible to phenoxy herbicides. Silvex and 2,4,5–T are more effective than 2,4–D. Silvex and 2,4,5–T at 1 to 1½ pounds per acre control this weed. Usually 2,4–D at 1½ to 2 pounds controls it, but it is not killed by 2,4–D even at a rate of 2 pounds. Curly indigo plants should be sprayed when they are 1 to 3 feet tall. Phenoxy herbicides should be applied when rice is in the "tolerant" stage of growth (p. 24).

Ducksalad

Heteranthera spp.

OTHER NAMES.—Mudplantain and waterlily.

PRINCIPAL SPECIES.—*Heteranthera limosa* (Sw.) Willd. (fig. 21) and *H. reniformis* R. & P.

DESCRIPTION.—Species of ducksalad are aquatic annuals that reproduce by seed. Leaf shape and flower number differentiate *Heteranthera limosa* and *H. reniformis.* Leaves of *H. limosa* are oval, narrow, and ½ to 5 inches long; the inflorescence has only one flower. Leaves of *H. reniformis* are kidney to heart shaped and 1 to 3 inches long and about as broad; the inflorescence has two or more flowers. Ducksalad seeds are borne in a dehiscent capsule that contains many minute, ridged, black seeds.

DISTRIBUTION.—Ducksalad is a serious rice-field weed in the southern ricegrowing area. It grows in the rice crop, in shallow water in irrigation and drainage canals, and in ditches, potholes, sloughs, and other wet areas. It is particularly troublesome in water-seeded rice. Seeds germinate under water as soon as the field is flooded. The young plants compete with rice early in the growing season and reduce yields.

CONTROL.—Land leveling, drainage, good rice stands, and herbicides help control ducksalad. Land leveling eliminates potholes and promotes drainage of the land. Ducksalad may be killed by thoroughly drying the soil to where it cracks open. Drying kills young plants more easily than old ones.

Herbicides, including propanil, 2,4,5–T, silvex, and 2,4–D, kill ducksalad. Propanil at 3 or 4 pounds per acre applied to very young

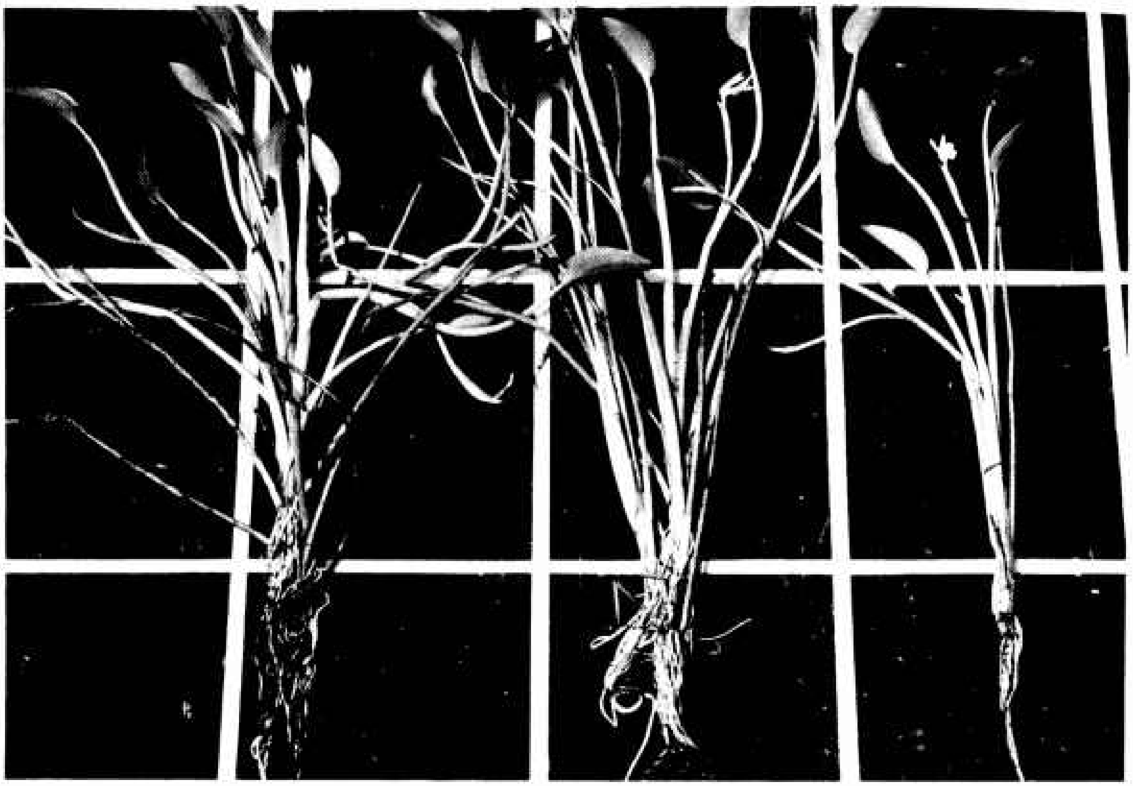

FIGURE 21.—Ducksalad (*Heteranthera limosa*).

ducksalad plants in the 1-leaf stage, or 1 to 2 inches tall, controls this weed, but it does not kill old or large ones. Silvex and 2,4,5–T at 1 to 1½ pounds per acre control ducksalad fairly well, but young plants are more easily controlled than old ones. Ducksalad is more susceptible to 2,4–D than to 2,4,5–T or silvex. It is controlled effectively by ¾ to 1½ pounds per acre of 2,4–D applied when rice is in the "tolerant" stage of growth (p. 24), but 2,4,5–T at 1½ pounds may give only partial control. If ducksalad becomes serious when rice is 4 to 6 weeks old, 2,4,5–T at ¾ to 1 pound per acre may be applied for partial control. Later, when rice is in the "tolerant" stage of growth, an application of 2,4–D may be required.

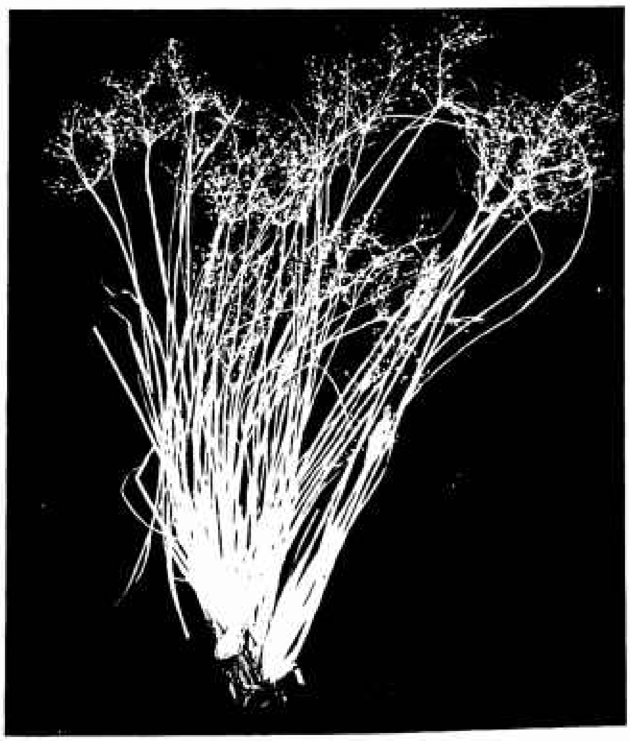

FIGURE 22.—Fimbristylis (*Fimbristylis miliacea*).

Fimbristylis (fig. 22)

Fimbristylis spp.

OTHER NAME.—Hoorahgrass.

PRINCIPAL SPECIES.—*Fimbristylis autumnalis* (L.) R. & S. and *F. miliacea* (L.) Vahl.

DESCRIPTION.—Species of *Fimbristylis* are annuals that reproduce by seed. Plants are turflike in growth. The culms are slender, erect to diffuse, leafy at the base, 12 to 18 inches tall at maturity, and weak; and they lodge easily. The leaf blades are narrow and short. The inflorescence is open and has several small foliagelike bracts of variable length at its base.

DISTRIBUTION.—Fimbristylis is troublesome only in the Southern United States. It grows in the rice crop, on field levees, along canals, and in other wet areas. It competes with rice and reduces yields.

CONTROL.—Fimbristylis is controlled by good seedbed preparation, proper water management, good stands of rice, and herbicides. Propanil at 3 to 4 pounds per acre kills young plants. Phenoxy herbicides, including 2,4–D, 2,4,5–T, and silvex, at ½ to 1½ pounds per acre control this weed. Phenoxy herbicides should be applied to rice in the "tolerant" stage of growth (p. 24).

Gooseweed (fig. 23)

Sphenoclea zeylanica Gaertn.

OTHER NAME.—Hollowstem.

PRINCIPAL SPECIES.—No others.

DESCRIPTION.—Gooseweed is an aquatic annual that reproduces by seed. Stems are erect, smooth, hollow, and 1 to 5 feet tall. Leaves are elliptical to linear, smooth margined, 1 to 4 inches long, light green—paler beneath than above. Flowers are borne in a continuous dense spike and are white or greenish.

DISTRIBUTION.—Gooseweed grows in the Southern United States. It grows in the rice crop where stands are thin, in irrigation and drainage canals, in ditches, along levees, and in other wet areas. It competes with rice and, when it is green and succulent, interferes with harvest.

CONTROL.—Gooseweed may be controlled by rotations, good seedbed preparation, cultivation, land leveling, drainage, good stands of rice, and herbicides. Where stands of rice are adequate and uniform and water is managed correctly, gooseweed is no problem.

Silvex, 2,4–D, and 2,4,5–T at 1 to 1½ pounds per acre will greatly reduce competition of gooseweed with rice. Sometimes, however, these herbicides give only partial control because gooseweed is relatively tolerant. Gooseweed is stunted by the treatment, but often recovers. Gooseweed is more susceptible to 2,4,5–T and silvex than to 2,4–D. The latter herbicide should be applied when rice is in the "tolerant" stage of growth (p. 24). Silvex and 2,4,5–T at ¾ to 1 pound per acre applied 4 or 5 weeks after emergence of rice give some control. Not more than 1 pound per acre should be applied at this time.

In uncultivated areas, such as ditches and drainage canals, 2,4–D, 2,4,5–T, or silvex may be applied at 2 to 4 pounds per acre to control gooseweed. Oil- or water-carried sprays may be used, but oil is more effective. Surfactants increase the effectiveness of the phenoxy herbicides applied as water sprays.

FIGURE 23.—Gooseweed (*Sphenoclea zeylanica*).

Knotgrass

Paspalum spp.

PRINCIPAL SPECIES AND COMMON NAMES.—*Paspalum distichum* L. called knotgrass, water bermudagrass, jointgrass, and lakegrass; *P. lividum* Trin. known commonly as longtom, doggrass, and watergrass; and *P. acuminatum*

Raddi. called brookpaspalum, watergrass, and crawlinggrass.

DESCRIPTION.—All principal species are perennials that reproduce by seed and creeping runners. *Paspalum distichum* has stolons often growing 25 feet long, and the leaf blades are relatively short—1 to 3 inches long. It has two racemes, or seed heads, which are ascending, often incurved, and 1 to 2 inches long. *P. lividum* is a smooth, creeping grass with culms 20 to 40 inches long. Leaf blades are 6 to 10 inches long and purple at the tip. The seedstalk bears several, usually 4 to 7, dark-purple racemes. *P. acuminatum* resembles *P. lividum*, but leaf blades are shorter and wider and have a very light-colored midrib. Seed heads bear 3 to 5, usually 3, erect or ascending racemes that are 2 to 3 inches long.

DISTRIBUTION.—Knotgrass grows in all rice-producing areas, but longtom and brookpaspalum grow only in southern Louisiana and Texas. They are usually most troublesome when the rice is young and in irrigation and drainage canals where they impede the movement of water. These weeds compete with rice and reduce yields.

CONTROL.—Species of knotgrass are controlled by cultural practices, such as good drainage, fallowing with intensive and timely cultivation in the summer, and good seedbed preparation. In the rice crop, cultural methods are useful because paspalums cannot be removed selectively from rice with herbicides. In canals, ditches, and other uncultivated areas, knotgrass and other paspalums may be controlled with dalapon at 5 to 10 pounds per acre applied when the creeping runners are 2 to 6 feet long. The spray volume should be sufficient to adequately cover the plants. Activity of dalapon on these weeds is enhanced by the addition of a surfactant at 0.1 percent by weight to the spray solution. Dalapon should not be sprayed on rice.

Mexican-weed (fig. 24)

Caperonia castaneaefolia (L.) St. Hil.

OTHER NAMES.—Birdeye and Texas-weed.

PRINCIPAL SPECIES.—No others.

DESCRIPTION.—Mexican-weed is a tough, fibrous-rooted annual that reproduces by seed. Leaves are alternate, about 2 inches wide, 3 to 5 inches long, prominently veined, coarsely toothed on margin, and petioled. The stem is rough, hairy, and 2 to 3 feet tall. It has small white flowers and a burlike fruit. Seeds are spherical, gray with distinctive light-colored markings, and about one-eighth inch in diameter.

DISTRIBUTION.—Mexican-weed is troublesome in Louisiana and Texas. It grows in the rice crops, on levees, and in other wet areas. It competes with rice, interferes with harvesting, and lowers quality because its seeds are difficult to separate from rough and milled rice.

CONTROL.—Rotations, good seedbed preparation, hand pulling, and herbicides control Mexican-weed. Silvex, 2,4,5-T, and 2,4-D at 1 to 1½ pounds per acre control this weed, but silvex and 2,4,5-T are more effective than 2,4-D. Apply phenoxy herbicides when rice is in the "tolerant" stage of growth (p. 24).

FIGURE 24.—Mexican-weed (*Caperonia castaneaefolia*).

Morningglory

Ipomoea spp.

PRINCIPAL SPECIES AND COMMON NAMES.—*Ipomoea lacunosa* L. called small-flowered morningglory (fig. 25); *I. hederacea* (L.) Jacq. called ivyleaf morningglory; and *I. purpurea* (L.) Roth called common morningglory.

FIGURE 25.—Small-flowered morningglory (*Ipomoea lacunosa*).

DESCRIPTION.—Species of morningglory are twining annuals that reproduce by seed. Stems are hairy and 3 to 15 feet long. Leaves of *Ipomoea lacunosa* and *I. purpurea* are heart shaped, but those of *I. hederacea* are deeply 3-lobed with rounded sinuses. Flowers are solitary on axillary peduncles or in clusters, funnel shaped, and white, purple, or pale blue. Seeds are about one-quarter inch long, are dark brown to black, and have one round and two flattened sides.

DISTRIBUTION.—Morningglories are troublesome in rice in the southern rice-producing areas. They grow on ricefield levees and on banks of irrigation and drainage canals. They do not grow in water; therefore, they are not troublesome between the levees. Morningglories interfere with harvest and lower the quality of rice because the seeds are difficult to separate from rough and milled rice.

CONTROL.—Rotation of row crops and rice, cultivation, and the use of herbicides help control morningglories. They may be controlled on ricefield levees by spraying with silvex, 2,4–D, or 2,4,5–T at ¾ to 1½ pounds per acre. Phenoxy herbicides should be applied when rice is in the "tolerant" stage of growth (p. 24). Propanil at 3 or 4 pounds per acre controls morningglories in the cotyledonary stage of growth, but it does not kill those having one or more leaves.

Red Rice (figs. 26 and 27)

Oryza sativa L.

OTHER NAMES.—Vermillion red rice, Italian red rice, and common red rice.

PRINCIPAL TYPES.—Red rice is a variety of rice, and there are many types.

DESCRIPTION.—Red rice is an annual that reproduces by seed. It usually matures before

FIGURE 26.—Red rice (*Oryza sativa*), whole plant.

white rice. It has a red seedcoat, which may vary in redness, instead of the usual brown one. It has a more spreading growth than white rice. The heads are loose, open, and lightly drooping. The grains shatter readily when ripe and may be short, medium, or long. Sometimes the grains must be hulled to expose the red seedcoat before red rice can be distinguished from the white rice. Some varieties have long awns on the spikelet.

FIGURE 27.—Red rice, panicles.

DISTRIBUTION.—Red rice is a serious weed in all rice-producing States. It grows in the rice crop, in irrigation and drainage canals, on levees, and in other wet areas. It reduces yields and quality of rough and milled rice. Kernels of red rice are difficult to separate from the milled white rice.

CONTROL.—Red rice is spread largely by using seed containing red grains. The use of high-quality rice seed prevents establishment of red rice on the land. Red rice is difficult to control once it is established, because the seeds shatter easily and persist in the soil for several years. Rotations, fallowing, cultivation, land leveling, and grazing help control red rice. When row crops are rotated with rice, red rice plants may be killed by cultivating the row crop. When a small grain crop, such as oats, is rotated with rice, the land may be summer fallowed with diskings timed to kill red rice plants. Disking brings dormant seeds to the soil surface, where they germinate and are killed by successive cultivations. The cultivation just before planting rice should be shallow to prevent bringing more red rice seed to the soil surface. When pasture is rotated with rice, the grazing prevents seed production of red rice. Hand pulling scattered plants in commercial rice to prevent red rice from spreading and becoming more serious is feasible where infestations are light.

Redstem (fig. 28)

Ammannia coccinea **Rothb.**

OTHER NAME.—Toothcup.

PRINCIPAL SPECIES.—*Ammannia coccinea* is the only species of economic importance in rice.

DESCRIPTION.—Redstem is an aquatic annual that reproduces by seed. Stems are square, often freely branched, and 8 to 40 inches tall. Leaves are narrow (about ½ inch wide), 1 to 4 inches long, and clasping at the base. Flowers are borne in the axils of the leaves. Seeds are produced in spherical capsules that are one-tenth to one-fifth inch in diameter. The plant turns red at maturity.

DISTRIBUTION.—Redstem is a serious rice-field weed in all rice-producing States. It grows in the rice crop, along levees, ditches, and canals, and in other wet areas. It grows especially well where rice stands are thin. It reduces yields, lowers quality, interferes with harvesting, and increases cost of drying when green capsules are present in rough rice.

CONTROL.—Rotations, good seedbed preparation, cultivation, good stands of rice, and herbicides control redstem. Redstem is very susceptible to phenoxy herbicides. Silvex, 2,4–D, 2,4,5–T, and MCPA at ½ to 1½ pounds per acre applied to plants 1 to 2 feet tall control this weed. Phenoxy herbicides should be applied when rice is in the "tolerant" stage of growth (p. 24). Propanil at 3 to 4 pounds per acre kills small redstem plants 2 inches tall, but it does not control large ones.

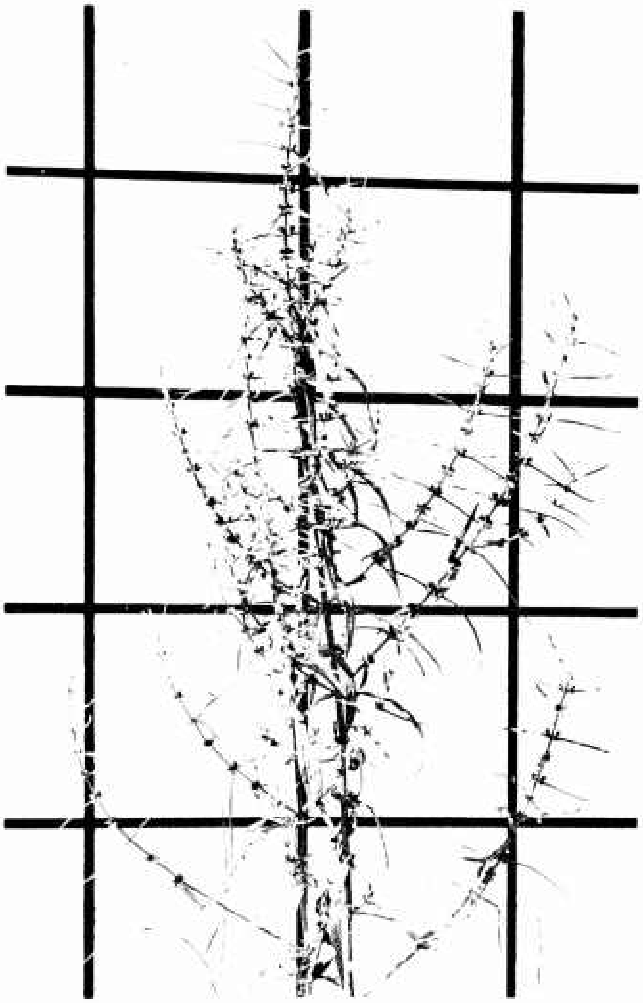

FIGURE 28.—Redstem (*Ammannia coccinea*).

Sesbania (fig. 29)

Sesbania exaltata (Raf.) Cory

OTHER NAMES.—Coffeebean, coffeeweed, tall-indigo, and sennabean.

PRINCIPAL SPECIES.—No others.

DESCRIPTION.—Sesbania is a tall, erect, smooth, leguminous annual that reproduces by seed. It may grow 12 to 15 feet tall. Leaves are compound, with 12 to 25 pairs of leaflets. Flowers are yellow and usually mottled with purple. Pods are long, narrow, compressed, and 6 to 12 inches long; they have numerous seeds separated by transverse partitions. Seeds are small and oblong; they may be viable in the soil for many years. Young plants of sesbania resemble those of curly indigo, but they may be identified by the small narrow bract or stipule, the smooth stem (fig. 20), and the simple leaf that emerges just after the cotyledons.

DISTRIBUTION.—Sesbania is a serious weed in the southern rice-producing areas, but it does not grow on the West Coast. It grows in the rice crop, on field levees, in uncultivated fields and waste areas, along canals and ditchbanks, in row crops, and other places. It competes with rice, interferes with harvest, and reduces quality because its seeds are difficult to remove from rough and milled rice.

CONTROL.—Sesbania is controlled by rotation, fallowing, cultivation, good land preparation, water seeding, hand pulling, and herbicides. Rotations of row crops or pasture and rice help control this weed. Sesbania may be controlled in row crops by cultivation and in pasture by grazing and mowing. Summer fallowing land with timely and thorough cultivation controls sesbania. Water seeding controls

FIGURE 29.—Sesbania (*Sesbania exaltata*) in rice.

sesbania because seeds do not germinate when they are covered with water. Hand pulling sesbania plants is practical when only a few scattered plants are present.

Sesbania may be controlled with 2,4–D, 2,4,5–T, and silvex at rates of 1 to 1½ pounds per acre. Plants should be sprayed when they are 2 to 6 feet tall. Phenoxy herbicides should be applied when rice is in the "tolerant" stage of growth (p. 24). Propanil at 2 to 3 pounds per acre kills young sesbania plants; it is most effective when the plants are 4 to 24 inches tall.

Smartweed (fig. 30)

Polygonum spp.

OTHER NAMES.—Knotweed and pepperweed.

PRINCIPAL SPECIES.—Numerous species of smartweed infest rice; therefore, no specific breakdown is given.

DESCRIPTION.—Some species of smartweed are annual herbs and others are perennial; some species grow erect and others are prostrate. The plants are usually 2 to 6 feet tall. The stems have thick joints, and the leaves are alternate, linear, and short petioled. Flowers are in axillary clusters or in spikes and panicles, often nodding. Seeds are a 3-angled achene, small, and dark brown to black; and they have a hard seedcoat.

DISTRIBUTION.—Smartweeds grow in all rice-producing States. They grow in the rice crop where cultivation and drainage are poor, on ricefield levees, in drainage and irrigation canals, in potholes and sloughs, and in other wet areas. Smartweeds often grow in shallow water since some are true aquatics, but others grow on uplands. They reduce rice yields, interfere with harvesting and drying, and lower quality of rice.

CONTROL.—Smartweeds are controlled by cultivation, good seedbed preparation, drainage, and herbicides. Smartweeds growing on ricefield levees may be partially controlled with 2,4–D, 2,4,5–T, silvex, or MCPA at rates of 1 to 1½ pounds per acre. Usually rates of 4 to 8 pounds are required to kill smartweeds, but rates of 1 to 1½ pounds inhibit growth and prevent seed production. Only rates of 1 to 1½ pounds may be used in the rice crop. Phenoxy herbicides should be applied when rice is in the "tolerant" stage of growth (p. 24). Smartweeds may be controlled in uncultivated areas, including canals, ditches, and reservoirs, with low-volatile esters of 2,4–D at 4 to 8 pounds per acre applied in fuel oil at 100 gallons per acre and with amitrole-T at 1 to 2 pounds applied in 100 to 200 gallons of water per acre.

FIGURE 30.—Smartweed (*Polygonum* spp.).

Spikerush (fig. 31)

Eleocharis spp.

PRINCIPAL SPECIES AND COMMON NAMES.—*Eleocharis obtusa* (Willd.) Schultes (annual) called blunt spikerush; *E. parvula* (R. & S.) Link (annual) called dwarf spikerush and niggerhair; *E. palustris* (L.) R. & S. (perennial) called creeping spikerush (fig. 32), common spikerush, and wiregrass; *E. quadrangulata* (Michx.) R. & S. (perennial) called square-stem spikerush or four-square; and others.

DESCRIPTION.—Species of this genus are annuals or perennials that reproduce by seed, or rhizomes, or both. Plants are turflike in growth and have simple, round culms that are erect or slightly reclining and terminated by a seed head. Leaves are bladeless sheaths. Plants of *Eleocharis obtusa* have blunt-tipped sheaths and are 12 to 20 inches tall at maturity. *E. parvula* is one of the smallest spikerushes; it grows only 1 to 4 inches tall. *E. palustris* has a creeping growth and grows about 3 feet tall. *E. quadrangulata* has stout, thick, sharply 4-angled culms growing to a height of 3 feet.

DISTRIBUTION.—Spikerushes grow in all rice-producing States. *Eleocharis palustris* is especially troublesome in California. Spikerushes grow in the rice crop, on field levees, in shallow ditches, and on poorly drained soil. *E. obtusa* and *E. parvula* are especially troublesome in water-seeded rice. They compete with rice in the early growing season and may reduce yields greatly.

CONTROL.—Spikerushes are controlled by drainage, adequate seedbed preparation, and deep and repeated cultivation. Presence of perennial spikerushes in ricefields often indicates poor seedbed preparation or poor drainage. *Eleocharis palustris* does not germinate well under continuous flooding; therefore, seeding rice in the water helps control it. Annual spikerushes, such as *E. obtusa* and *E. parvula,*

FIGURE 31.—Blunt spikerush (*Eleocharis obtusa*).

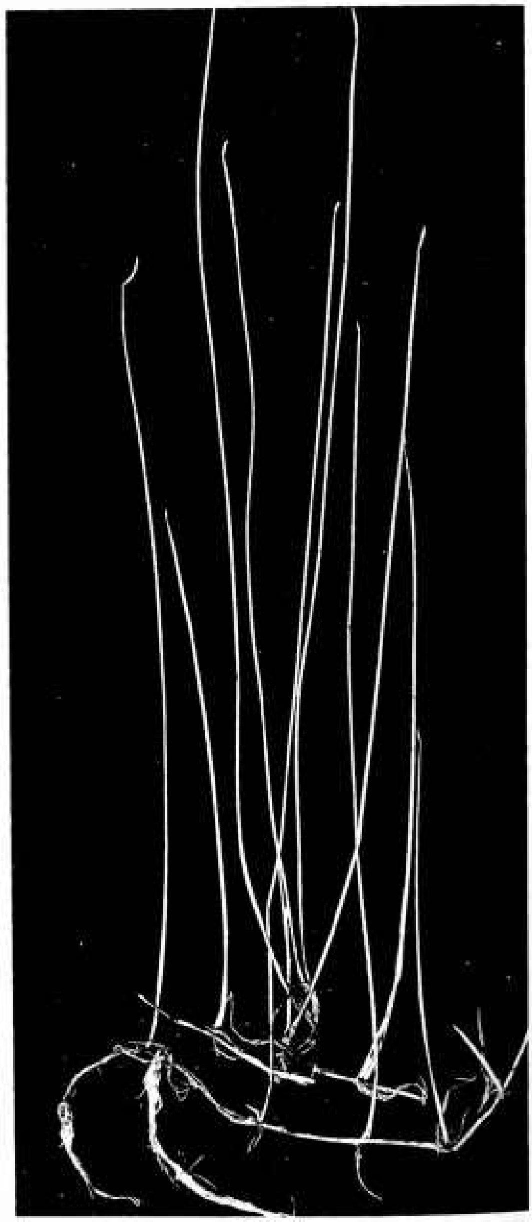

FIGURE 32.—Creeping spikerush (*Eleocharis palustris*).

are controlled with herbicides, including propanil, 2,4–D, MCPA, 2,4,5–T, and silvex. Propanil at 3 to 4 pounds per acre kills young annual spikerush plants. Phenoxy herbicides at ½ to 1½ pounds per acre kill young or old annual spikerushes. They should be applied to rice in the "tolerant" stage of growth (p. 24). Perennial spikerushes infesting rice cannot be controlled with herbicides because 4 to 8 pounds per acre is required for control. When spikerushes grow in uncultivated areas, they may be controlled with 2,4-D, 2,4,5-T, or silvex at 4 to 8 pounds per acre in sufficient water or fuel oil to cover foliage.

Sprangletop (figs. 33 and 34)

Leptochloa spp.

OTHER NAMES.—Raygrass, Christmastree-grass, and feathergrass.

PRINCIPAL SPECIES.—*Leptochloa panicoides* (Presl.) Hitchc. and *L. fascicularis* (Lam.) Gray.

DESCRIPTION.—Species of sprangletop which are weeds in rice are annuals that reproduce from very small seeds seldom found in rough rice. The plants have fine stems terminated in a panicle, grow 2 to 3 feet tall, and tiller heavily.

DISTRIBUTION.—Sprangletop is present in all rice-producing States. *Leptochloa panicoides* does not grow in California, but it grows in the other rice-producing States. Sprangletop grows in shallow water along canals, in the rice crop, and on field levees. It is particularly serious where stands of rice are thin. It grows especially well on the heavy clay soils in the Mississippi River bottom lands.

CONTROL.—Seeds of sprangletop do not germinate well under water, but after germination the young plants grow through water more quickly than rice does. Water seeding discourages sprangletop, and a good stand of rice helps control it. Propanil at 3 or 4 pounds per acre usually does not control *Leptochloa fascicularis*, but these rates applied postemergence to young plants in the 1- to 2-leaf stage reduce competition of *L. panicoides* with rice.

FIGURE 33.—Sprangletop (*Leptochloa panicoides*).

FIGURE 34.—Sprangletop (*Leptochloa fascicularis*).

Umbrellasedge

Cyperus spp.

Principal Species and Common Names.—*Cyperus erythrorhizos* Muhl. (fig. 35) (annual) called redroot flatsedge; *C. articulatus* L. (perennial) called jointed flatsedge, jointed sedge, and onions; *C. Iria L.* (fig. 36) (annual) called umbrellasedge; *C. difformis* L. (annual) called sedge; *C. strigosus* L. (perennial) called straw-colored sedge (fig. 37); and *C. esculentus* L. (perennial) called yellow nutsedge.

Figure 35.—Redroot flatsedge (*Cyperus erythrorhizos*).

Description.—Species of this genus are annuals and perennials that reproduce by seed or tubers, or both. The general appearance of plants within each species of *Cyperus* may vary greatly. The plants of most species of *Cyperus* have a triangular flower stalk bearing a headlike or branch inflorescence. At the base of the inflorescence there are foliagelike bracts that vary in size and number in the various species. Most umbrellasedge plants grow 1 to 2 feet tall.

Figure 36.—Umbrellasedge (*Cyperus Iria*).

Distribution.—Umbrellasedges grow in all rice-producing States. *Cyperus erythrorhizos* and *C. Iria* are troublesome in the southern rice-producing areas and *C. difformis* is prevalent in California. They grow in the rice crop, in and along irrigation and drainage canals, on levees, in sloughs, and in other poorly drained areas. The perennial types, except *C. esculentus*, usually are prevalent in poorly drained areas, such as idle ricefields; but may infest rice when seedbed preparation is inadequate. The annual umbrellasedges are more troublesome in the rice crop than perennials. *C. erythrorhizos*, *C. Iria*, and *C. difformis* are especially troublesome where rice stands are thin; they ordinarily appear late in the season after the land has been submerged for some time. Umbrellasedges reduce yields, interfere with harvesting, and lower rice quality.

Control.—Rotations, land preparation, cultivation, drainage, good rice stands, and herbicides help control umbrellasedges. Some umbrellasedges, especially annuals, may infest ricefields even with good cultural practices. Silvex, MCPA, 2,4–D, and 2,4,5–T at 1 to 1½ pounds

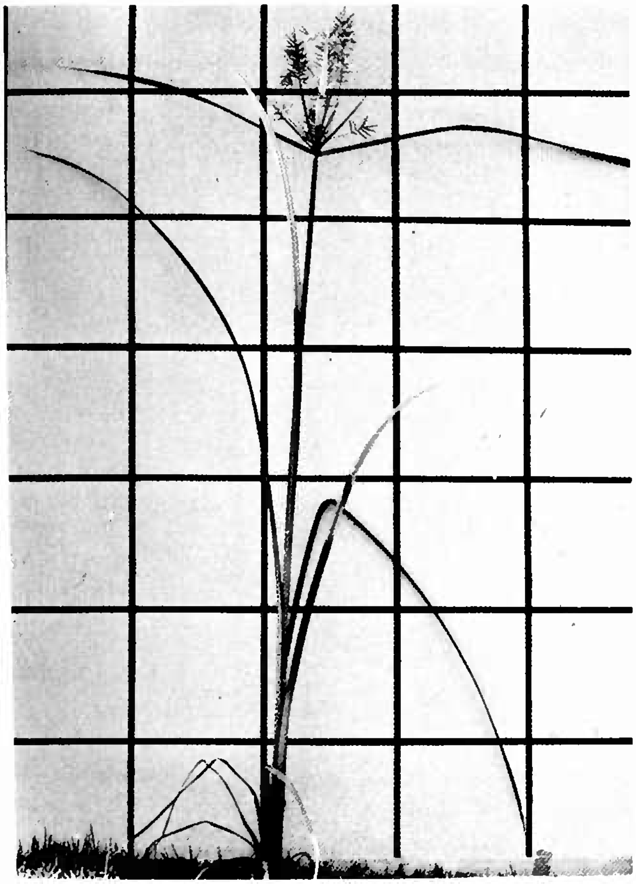

FIGURE 37.—Straw-colored sedge (*Cyperus strigosus*).

per acre control *Cyperus erythrorhizos, C. Iria*, and some other annual sedges, but they do not control *C. difformis* satisfactorily. Phenoxy herbicides, however, may give partial control of some of the perennial sedges. Phenoxy herbicides should be applied to rice during the "tolerant" stage of growth (p. 24). Propanil at 3 to 4 pounds per acre controls young umbrellasedge; it usually controls the annuals better than the perennials.

Waterhyssop (fig. 38)

Bacopa rotundifolia (Michx.) Wettst.

OTHER NAMES.—No others.

PRINCIPAL SPECIES.—*B. rotundifolia* is the only species of economic importance in rice.

DESCRIPTION.—Waterhyssop is an aquatic annual that reproduces by seed. Stems, 8 to 24 inches long, are submerged with the tips floating; they are pubescent when young. Leaves are thin, round, clasping at the base, and palmately veined. Flowers, 2 to 4 at each node, are white with a yellow throat, pediceled, and axillary.

DISTRIBUTION.—Waterhyssop grows in all ricegrowing States. It is usually associated with other aquatic weeds, such as ducksalad; and it is most serious where stands of rice are thin or where rice is seeded in water. It grows in the rice crop, shallow ditches and

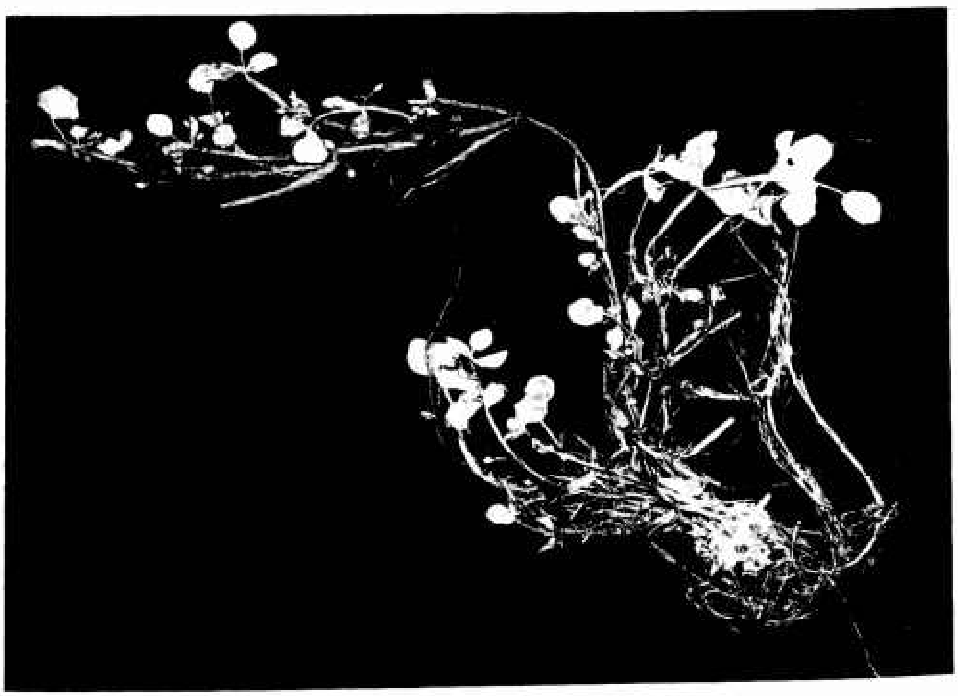

FIGURE 38.—Waterhyssop (*Bacopa rotundifolia*).

canals, and other wet areas. It competes with rice during the early growing season and may reduce tillering and yields.

CONTROL.—Waterhyssop is controlled by drainage, good rice stands, and herbicides. It is very susceptible to phenoxy herbicides. Silvex, 2,4–D, MCPA, and 2,4,5–T at ½ to 1 pound per acre control it effectively. Silvex and 2,4, 5–T may be applied as early as 4 or 5 weeks after emergence and MCPA may be applied as early as 6 weeks after emergence without damaging rice. However, 2,4–D should not be applied until the rice is in the "tolerant" stage of growth (p. 24).

Waterplantain (fig. 39)

Alisma triviale Pursh

OTHER NAMES.—Common waterplantain and waterlily.

PRINCIPAL SPECIES.—*Alisma triviale* is the only species of economic importance in rice.

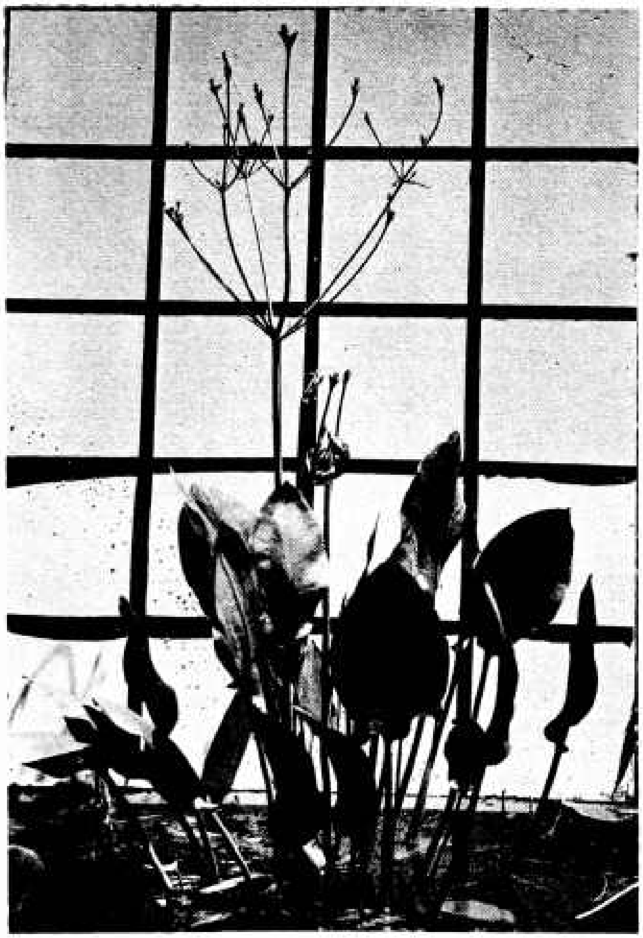

FIGURE 39.—Waterplantain (*Alisma triviale*).

DESCRIPTION.—Waterplantain is an emersed, erect, aquatic perennial that reproduces by seed and rootstocks. Plants may grow 48 inches tall. Leaves are long petioled with elliptical blades up to 10 inches long and 6 inches wide. The inflorescence is pyramid shaped and branched. Seeds are round, reddish brown, and about one-tenth inch long. Seeds may remain viable in the soil for many years.

DISTRIBUTION.—Waterplantain is a weed in rice in California only. It grows in ricefields where stands are thin, on banks and edges of irrigation and drainage canals, and in other wet areas. Seeds of waterplantain germinate under water and at a lower temperature than rice. It often grows abundantly where cold water enters the ricefield.

CONTROL.—Waterplantain may be controlled by good stands of rice; by allowing the weed seeds to germinate in water, followed by drainage, drying, and cultivation; and by herbicides. It may be killed by spraying with 2,4–D or MCPA at ¾ to 1½ pounds per acre. Phenoxy herbicides should be applied when rice is in the "tolerant" stage of growth (p. 24).

Waterprimrose

Jussiaea spp.

OTHER NAME.—Primrose-willow.

PRINCIPAL SPECIES AND COMMON NAMES.—*Jussiaea decurrens* (Walt.) DC. (fig. 40) called winged waterprimrose and *J. repens* L. var. *glabrescens* Ktze. (fig. 41) called creeping waterprimrose.

DESCRIPTION.—*Jussiaea decurrens* is an aquatic annual that reproduces by seed. Stems are erect, 3 to 6 feet tall, smooth, 4-angled; leaves are narrow, linear, and sessiled; capsules are slender, 4-angled, and ½ to 1 inch long. *J. repens* var. *glabrescens* is an aquatic perennial that reproduces by seed, stems, and rootstocks. Stems are smooth, prostrate or floating, ascending at the tips, and rooting at the nodes; leaves are smooth, oblong, 1 to 4 inches long, and petioled; capsules are almost cylindrical and 1 to 2 inches long.

DISTRIBUTION.—Waterprimroses grow mainly in the southern rice-producing areas. They grow in field bar ditches, irrigation and drainage canals, ditches, and other wet areas. *Jussiaea repens* var. *glabrescens* grows in dense beds in ponds and ditches (fig. 42). Waterprimroses are not generally troublesome in the rice crop, but they may grow where rice stands are thin. They compete with rice, interfere with harvesting and drying, lower rice quality, and impede flow of water in canals and ditches.

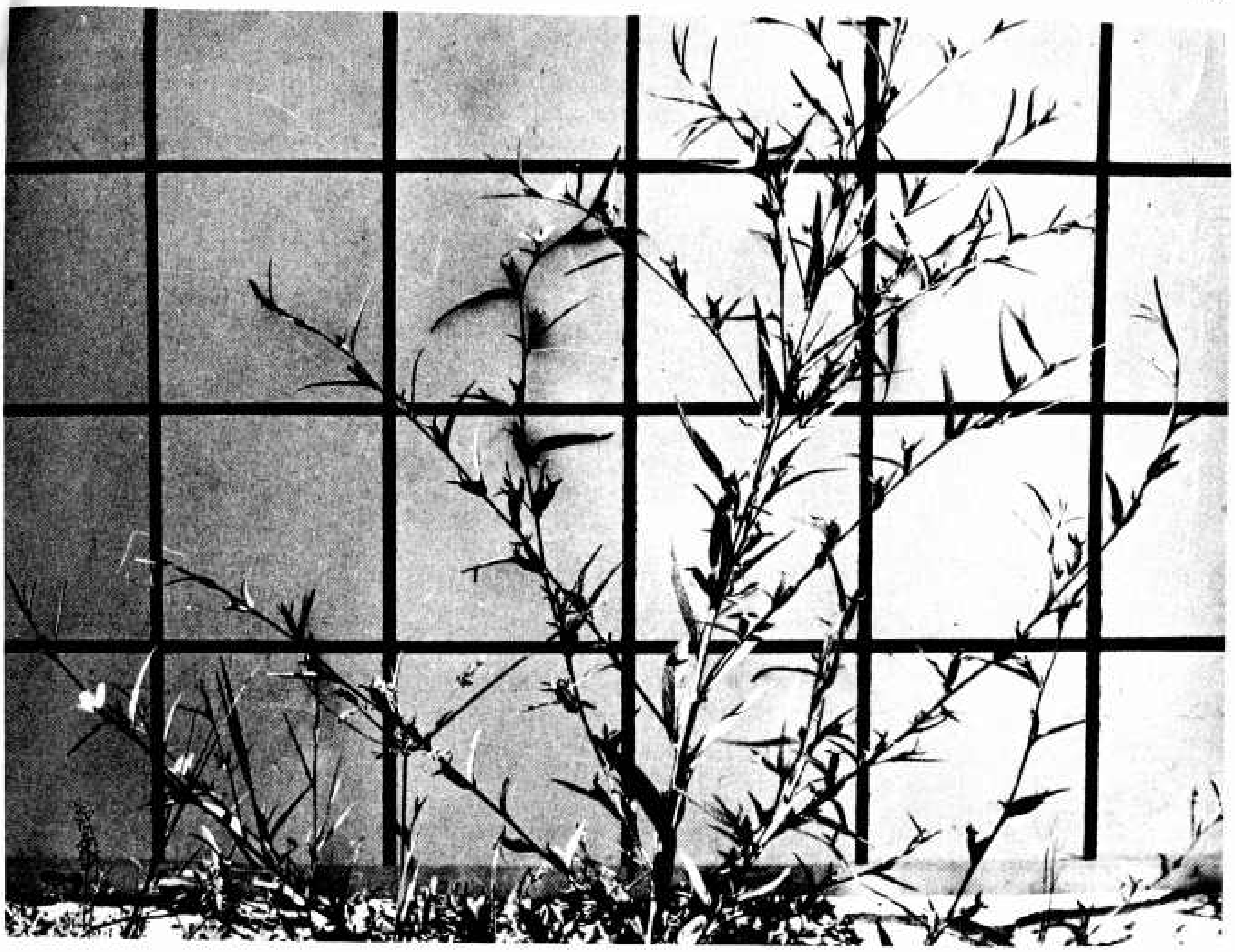

FIGURE 40.—Winged waterprimose (*Jussiaea decurrens*).

FIGURE 41.—Creeping waterprimrose (*Jussiaea repens* var. *glabrescens*).

CONTROL.—Cultural methods, such as cultivation, good seedbed preparation, good rice stands, and drainage, are used to control waterprimrose in ricefields. Waterprimroses cannot be selectively killed in ricefields with herbicides, but they can be controlled in uncultivated areas. They are susceptible to 2,4-D at 2 to 8 pounds per acre applied in 100 gallons of oil or water. Oil-carried sprays are more effective than water-carried ones, which usually require surfactants.

FIGURE 42.—A creeping waterprimrose bed in a drainage ditch.

BIBLIOGRAPHY

(1) ADAIR, C. R., and ENGLER, KYLE.
1955. THE IRRIGATION AND CULTURE OF RICE. *In* Water, U.S. Dept. Agr. Yearbook, pp. 389–394.

(2) AKESSON, N. B., and HARVEY, W. A.
1948. CHEMICAL WEED CONTROL EQUIPMENT. Calif. Agr. Expt. Sta. Cir. 389, 49 pp., illus.

(3) ARAI, M., and MIYAHARA, M.
1962. PHYSIOLOGICAL AND ECOLOGICAL STUDIES ON BARNYARDGRASS. Crop Sci. Soc. Japan, Proc. 31(1): 73–77.

(4) ——— and MIYAHARA, M.
1962. PHYSIOLOGICAL AND ECOLOGICAL STUDIES ON BARNYARDGRASS. Crop Sci. Soc. Japan, Proc. 31(2): 186–189.

(5) ARKANSAS AGRICULTURAL EXTENSION SERVICE and UNITED STATES DEPARTMENT OF AGRICULTURE.
1963. RECOMMENDED CHEMICALS FOR WEED AND BRUSH CONTROL—ARKANSAS 1963. Ark. Agr. Ext. Serv. Misc. Pub. 44, 16 pp. (Revised.)

(6) ——— and UNITED STATES DEPARTMENT OF AGRICULTURE.
1963. TIMING OF NITROGEN FOR RICE—RICE FERTILIZER RECOMMENDATIONS. Ark. Agr. Ext. Serv., February, 1 p.

(7) ARKANSAS STATE PLANT BOARD.
1957. OFFICIAL STANDARDS FOR SEED CERTIFICATION IN ARKANSAS. Ark. State Plant Board Cir. 15, 25 pp. (Revised.)

(8) BAKER, J. B.
1960. AN EXPLANATION FOR THE SELECTIVE CONTROL OF BARNYARDGRASS IN RICE WITH CIPC. Weeds 8(1): 39–47, illus.

(9) ———
1961. RICE WEED CONTROL. La. Agr. Expt. Sta., Rice Expt. Sta. Ann. Prog. Rpt. 49: 144–150.

(10) ——— HUDGINS, H. R., and SMITH, R. J., JR.
1962. ECONOMIC DATA ON LOSSES DUE TO WEEDS. South. Weed Conf. Res. Rpt. 15: 167–168.

(11) BARTON, L. V.
1962. THE GERMINATION OF WEED SEEDS. Weeds 10(3): 174–182.

(12) BEACHER, R. L.
1952. RICE FERTILIZATION. Ark. Agr. Expt. Sta. Bul. 522, 32 pp.

(13) BINGHAM, S. W., EASLEY, TILDON, EDWARDS, F. E., and others.
1958. WEED CONTROL RECOMMENDATIONS. Miss. Agr. Expt. Sta. Bul. 556, 36 pp., illus.

(14) BOHMONT, D. W.
1953. WEEDS OF WYOMING. Wyo. Agr. Expt. Sta. Bul. 325, 160 pp., illus.

(15) BRANDES, G. A.
1962. STAM F-34 PROVED SUCCESSFUL FOR GRASS AND WEED CONTROL IN RICE. Rice Jour. 65(1): 8, 10, 12, 37–39, illus.

(16) ———
1963. A PROGRESS REPORT OF STAM F–34 FOR GRASS AND WEED CONTROL IN RICE. Rice Jour. 66(1): 6–11, illus.

(17) CAFFEY, H. R., BOWMAN, D. H., and FISHER, CHARLES.
1962. CHEMICAL CONTROL OF GRASS IN RICE. Miss. Farm Res. 25(4): 2.

(18) CARRIER, LYMAN.
1917. THE IDENTIFICATION OF GRASSES BY THEIR VEGETATIVE CHARACTERS. U.S. Dept. Agr. Dept. Bul. 461, 30 pp., illus.

(19) COLEMAN, P. G., HAYNES, D. W. M., and HITCHCOCK, J. L. B.
1956. OBSERVATIONS ON THE CONTROL OF WEEDS IN PADI FIELDS BY THE USE OF HERBICIDES. Malayan Agr. Jour. 39(3): 191–199, illus.

(20) CRAFTS, A. S.
1961. THE CHEMISTRY AND MODE OF ACTION OF HERBICIDES. 269 pp., illus. New York and London.

(21) DANIELSON, L. L., KLINGMAN, D. L., SHAW, W. C., and others, compilers.
1961. SUGGESTED GUIDE FOR CHEMICAL CONTROL OF WEEDS. U.S. Agr. Res. Serv. ARS 22–67, 60 pp.

(22) DAVIS, L. L.
1950. CALIFORNIA RICE PRODUCTION. Calif. Agr. Ext. Serv. Cir. 163, 56 pp., illus.

(23) DAVIS, W. C.
1954. RESPONSES OF RICE TO SOME HERBICIDES. Tex. Agr. Expt. Sta. Prog. Rpt. 1678, 4 pp.

(24) ———
1954. WEED INVESTIGATIONS. Rice Tech. Com. Proc. 6: 19–21.

(25) ———
1955. WEED KILLERS AND RICE. Tex. Agr. Expt. Sta. Prog. Rpt. 1812, 4 pp.

(26) DE LA FUENTE, R. K., FERTIG, S. N., and LLENA, P. A.
1956. THE EFFECT OF TWO HERBICIDES ON RICE PLANTS SPRAYED AT DIFFERENT STAGES OF GROWTH. Philippine Agr. 40(7): 352–360, illus.

(27) DREESSEN, JACK.
1959. PESTICIDE LAW MANUAL. Natl. Agr. Chem. Assoc. Washington, D. C.

(28) DUNHAM, R. S.
1961. HERBICIDE MANUAL FOR MILITARY INSTALLATIONS. U.S. Dept. of the Navy, 141 pp.

(29) DUNSHEE, C. F.
1928. RICE EXPERIMENTS IN SACRAMENTO VALLEY 1922–1927. Calif. Agr. Expt. Sta. Bul. 454, 16 pp., illus.

(30) EDWARDS, F. E.
1957. SPRAYERS FOR WEED CONTROL IMPROVED. Miss. Farm Res. 20(4): 7, illus.

(31) ENNIS, W. B., JR.
1958. THE CHALLENGES OF MODERN WEED CONTROL. Weeds 6(4): 363–369.

(32) FERNALD, M. L.
1950. GRAY'S MANUAL OF BOTANY. 1632 pp., illus. New York.

(33) FINFROCK, D. C., VISTE, K. L., HARVEY, W. A., and MILLER, M. D.
1958. WEED CONTROL IN RICE. Calif. Agr. Ext. Serv. Leaflet 97, 2 pp. illus.

(34) FRENCH, G. W., and GAY, W. B.
1963. WEED CONTROL IN RICE FIELDS. World Crops 15(5): 196–199, 201–204, 206, illus.

(35) GARD, L. N., and RUDD, G.
1953. HERBICIDE DETERMINATION: ISOPROPYL N-(3-CHLOROPHENY) CARBAMATE (CIPC) IN SOIL AND CROPS. Jour. Agr. and Food Chem. 1: 630–632.

(36) GLEASON, H. A.
1952. THE NEW BRITTON AND BROWN ILLUSTRATED FLORA OF THE NORTHEASTERN UNITED STATES AND ADJACENT CANADA. 3 v., illus. Lancaster, Pa.

(37) GRIST, D. H.
1959. RICE. Ed. 3, 466 pp., illus. New York.

(38) HALL, VERNON, BRYAN, BILLY, ENGLER, KYLE, and others.
1963. PLASTIC LEVEES IN RICE IRRIGATION. Ark. Farm Res. 12(1): 4, illus.

(39) HARDCASTLE, W. S.
1962. AQUATIC WEEDS. South. Weed Conf. Res. Rpt. 15: 115–126.

(40) HEIKES, P. E.
1959. WEED CONTROL EQUIPMENT. Mont. State Col. Ext. Bul. 300, 24 pp., illus.

(41) HITCHCOCK, A. S.
1950. MANUAL OF THE GRASSES OF THE UNITED STATES. Ed. 2, 1051 pp., illus. Washington, D. C.

(42) HODGES, R. J.
1962. CONTROL OF GRASS AND WEEDS IN RICE. Tex. Agr. Ext. Serv. Rice Notes and Quotes 5(8): 1–2.

(43) HUDGINS, H. R.
1961. CHEMICAL CONTROL OF BARNYARDGRASS IN THE TEXAS RICE BELT. South. Weed Conf. Proc. 14: 107–110.

(44) ———
1962. CONTROL OF BARNYARDGRASS IN RICE WITH DPA. Tex. Agr. Expt. Sta. Prog. Rpt. 2229, 4 pp.

(45) JOHNSON, F. S.
1952. REPORT ON PRELIMINARY INVESTIGATION ON CHEMICAL WEED CONTROL IN VENEZUELA 1951. Internatl. Basic Econ. Corp. Res. Inst. Rpt. 2, 20 pp., illus.

(46) JOHNSTON, T. H., CRALLEY, E. M., and HENRY, S. E.
1959. PERFORMANCE OF RICE VARIETIES IN ARKANSAS, 1953–1958. Ark Agr. Expt. Sta. Rpt. Ser. 85, 31 pp.

(47) JONES, J. W.
1926. EXPERIMENTS IN RICE CULTURE AT THE BIGGS RICE FIELD STATION IN CALIFORNIA. U.S. Dept. Agr. Dept. Bul. 1387, 39 pp., illus.

(48) ———
1933. EFFECT OF DEPTH OF SUBMERGENCE ON THE CONTROL OF BARNYARDGRASS AND YIELD OF RICE GROWN IN POTS. Amer. Soc. Agron. Jour. 25(9): 578–583.

(49) ——— DAVIS, L. L., and WILLIAMS, A. H.
1950. RICE CULTURE IN CALIFORNIA. U.S. Dept. Agr. Farmers' Bul. 2022, 32 pp., illus.

(50) ——— DOCKINS, J. O., WALKER, R. K., and DAVIS, W. C.
1952. RICE PRODUCTION IN THE SOUTHERN STATES. U.S. Dept. Agr. Farmers' Bul. 2043, 36 pp., illus.

(51) KAPP, L. C., and BARTHOLOMEW, R. P.
1947. THE EFFECT OF CONTROLLING WEEDS BY IRRIGATION AND SEEDING PRACTICES ON RICE YIELDS. Ark. Agr. Expt. Sta. Bul. 467, 7 pp.

(52) KAUFMAN, P. B.
1953. GROSS MORPHOLOGICAL RESPONSES OF THE RICE PLANT TO 2,4–D. Weeds 2(4): 223–255, illus.

(53) ———
1955. HISTOLOGICAL RESPONSES OF THE RICE PLANT (*ORYZA SATIVA*) TO 2,4–D. Amer. Jour. Bot. 42(7): 649–659, illus.

(54) ——— and CRAFTS, A. S.
1956. RESPONSE OF THE RICE PLANT TO DIFFERENT FORMULATIONS AND METHODS OF APPLICATION OF 2,4–D, MCPA, AND 2,4,5–T. Hilgardia 24: 411–453, illus.

(55) KLINGMAN, D. L., and SHAW, W. C.
1962. USING PHENOXY HERBICIDES EFFECTIVELY. U.S. Dept. Agr. Farmers' Bul. 2183, 24 pp., illus.

(56) KLINGMAN, G. C.
1961. WEED CONTROL: AS A SCIENCE. 421 pp., illus. New York and London.

(57) LEWIS, D. C., SCOTT, V. H., MUELLER, K. E., and others.
1962. NEW RICE LEVEE CONCEPTS. Rice Jour. 65(4): 6–15, illus.

(58) MCRAE, D. H., WILSON, H. F., and SATTERTHWAITE, S. T.
1961. THE RESPONSE OF RICE AND WEEDS TO 3′,4′-DICHLOROPROPIONANILIDE AND TO RELATED ANILIDES. South. Weed Conf. Proc. 14: 321–324.

(59) MARTIN, A. C., ERICKSON, R. C., and STENNIS, J. H.
1957. IMPROVING DUCK MARSHES BY WEED CONTROL. U.S. Fish and Wildlife Serv. Cir. 19, 60 pp., illus. (Revised.)

(60) MATSUBAYASHI, M., ITO, R., NOMOTO, T., TAKASE, T., and YAMADA, N., compilers.
1963. THEORY AND PRACTICE OF GROWING RICE. 502 pp., illus. Tokyo.

(61) MEYER, B. S., and ANDERSON, D. B.
1939. UTILIZATION OF MINERAL SALTS. *In* Plant Physiology, pp. 415–436, illus. New York.

(62) MILLIGAN, TOM.
1957. TWICE THE RICE AT A PRACTICAL PRICE. Farm and Ranch 87(4): 20, illus.

(63) NEFF, J. A., and MEANLEY, BROOKE.
1957. BLACKBIRDS AND THE ARKANSAS RICE CROP. Ark. Agr. Expt. Sta. Bul. 584, 89 pp., illus.

(64) NELSON, MARTIN.
1944. ROTATION, CULTURAL, AND IRRIGATION PRACTICES AFFECTING RICE PRODUCTION. Ark. Agr. Expt. Sta. Bul. 445, 45 pp.

(65) NESTER, R. P.
1962. FOR MORE RICE PROFIT CONTROL BARNYARDGRASS. Ark. Agr. Ext. Serv. Leaflet 288, 8 pp., illus. (Revised.)

(66) ———
1963. STAGES OF DEVELOPMENT OF RICE VARIETIES IN ARKANSAS. Rice Jour. 66(3): 31–32.

(67) ———
1964. RICE PRODUCTION IN ARKANSAS. Ark. Agr. Ext. Serv. Cir. 476, 35 pp. (Revised.)

(68) ODGLEN, G. E., and WARREN, L. O.
1962. THE RICE STINK BUG, *OEBALUS PUGNAX* F., IN ARKANSAS. Ark. Agr. Expt. Sta. Rpt. Ser. 107, 24 pp., illus.

(69) OLSEN, K. L.
1957. "SCUM" CONTROL IN RICE FIELDS AND IRRIGATION CANALS. Ark. Agr. Expt. Sta. Rpt. Ser. 69, 20 pp., illus.

(70) ORSENIGO, J. R.
1956. RICE INVESTIGATIONS IN VENEZUELA IN 1954. Internatl. Basic Econ. Corp. Res. Inst. Rpt. 8, 28 pp., illus.

(71) PHILLIPS, P. J., and JUDD, MORROW.
1963. AN EVALUATION OF HIGH VISCOSITY, CROWDED PHASE EMULSIONS AS HERBICIDE CARRIERS WHEN APPLIED THROUGH THE BIFLUID SPRAY SYSTEM. Southwest Agr. Inst. Prog. Rpt. Sp–7b, 88 pp., illus.

(72) PRINCE, A. H.
1927. WEEDS AND GRASSES IN ARKANSAS RICE FIELDS. Ark. Agr. Ext. Serv. Cir. 253, 12 pp., illus.

(73) ROBBINS, W. W., CRAFTS, A. S., and RAYNOR, R. N.
1952. WEED CONTROL. 503 pp., illus. New York and London.

(74) ROHM AND HAAS CO.
1963. STAM F–34 AERIAL APPLICATION MANUAL FOR GRASS AND WEED CONTROL IN RICE. Ag–172a, 10 pp., illus. Philadelphia.

(75) ———
1963. STAM F–34 FOR GRASS AND WEED CONTROL IN RICE. Ag–190, 16 pp., illus. Philadelphia.

(76) ———
1964. STAM F–34. EX–A–73, 8 pp. Philadelphia.

(77) SCOTT, V. H., LEWIS, D. C., FOX, D. R., and BABB, A. F.
1961. PLASTIC LEVEES FOR RICE IRRIGATION. Calif. Agr. 15(11): 8–9.

(78) SEAMAN, D. E., BLACKBURN, R. D., and WELDON, L. W.
1961. SUGGESTED CONTROL MEASURES FOR COMMON AQUATIC WEEDS OF FLORIDA. U.S. Agr. Res. Serv., Crops Res. Div. Prog. Rpt. 42–61, 10 pp.

(79) SHAW, W. C.
1963. RECENT TECHNOLOGICAL ADVANCES IN WEED CONTROL. Rice Tech. Working Group Proc., Feb. 1962, 10: 12–14.

(80) ———
1964. WEED SCIENCE—REVOLUTION IN AGRICULTURAL TECHNOLOGY. Weeds 12(3): 153–162.

(81) ——— ALLEN, W. W., ASHTON, F. M., and others.
1962. REPORT OF THE TERMINOLOGY COMMITTEE, WEED SOCIETY OF AMERICA. Weeds 10(3): 255–271.

(82) SIERRA, J. N.
1957. EFFECTS OF HERBICIDES ON WEED SPECIES IN LOWLAND AND UPLAND RICE FIELDS. Philippine Agr. 41(3): 171–190.

(83) SLIFE, F. W., BUCHHOLTZ, K. P., and KOMMEDAHL, T.
1960. WEEDS OF THE NORTH CENTRAL STATES. Ill. Agr. Expt. Sta. Cir. 718, 262 pp., illus.

(84) SMALL, J. K.
1933. MANUAL OF THE SOUTHEASTERN FLORA. 1554 pp., illus. Chapel Hill, N. C.

(85) SMITH, R. J., JR.
1956. WEED CONTROL IN RICE IN THE SOUTHERN UNITED STATES. Rice Tech. Working Group Proc. 7: 18–20.

(86) ———
1958. THE DIFFERENTIAL VARIETAL RESPONSES OF RICE TO 2,4–D AS INFLUENCED BY THE STAGE OF GROWTH AND RATE OF APPLICATION. Rice Jour. 61(10): 18–19, 26–27, illus.

(87) ———
1960. CHEMICAL CONTROL OF BARNYARDGRASS IN RICE. Weeds 8(2): 256–267, illus.

(88) ———
1960. EFFECT OF LOW RATES OF SEVERAL PHENOXYALKYLCARBOXYLIC ACIDS ON SOYBEANS. South. Weed Conf. Proc. 13: 243–244.

(89) ———
1960. EFFECT OF POST-EMERGENCE APPLICATIONS OF SEVERAL PHENOXYCARBOXYLIC ACIDS ON RICE. (Abstract) Weed Soc. Amer., pp. 5–6.

(90) ———
1960. NITROGEN MANAGEMENT IN RICE INFESTED WITH BARNYARDGRASS. Ark. Farm Res. 9(1): 2, illus.

(91) ———
1960. 3,4-DICHLOROPROPIONANILIDE: A PROMISING NEW HERBICIDE FOR CONTROL OF BARNYARDGRASS IN RICE. South. Weed. Conf. Proc. 13: 245–247.

(92) ———
1961. CONTROLLING BARNYARDGRASS IN RICE WITH 3,4-DICHLOROPROPIONANILIDE. South. Weed. Conf. Proc. 14. 104–106.

(93) ———
1961. 3,-4-DICHLOROPROPIONANILIDE FOR CONTROL OF BARNYARDGRASS IN RICE. Weeds 9(2): 318–322, illus.

(94) ———
1962. WEED INVESTIGATIONS IN RICE. Rice Jour. 65(7): 42–44.

(95) ———
1963. CONTROL OF BROADLEAVED WEEDS AND WEED GRASSES IN RICE. Rice Tech. Working Group Proc., Feb. 1962, 10: 11–12.

(96) ——— BAKER, J. B., and HUDGINS, H. R.
1962. WEEDS IN RICE. South. Weed Conf. Res. Rpt. 15: 48–51.

(97) ——— and ENNIS, W. B., JR.
1953. STUDIES ON THE DOWNWARD MOVEMENT OF 2,4–D, AND 3–CHLORO–IPC IN SOILS. South. Weed Conf. Proc. 6: 63–71.

(98) ——— VISTE, K. L., and SHAW, W. C.
1959. PROGRESS IN WEED CONTROL IN RICE PRODUCTION IN THE UNITED STATES. Internatl. Rice Comn. News Letter 8(3): 1–6.

(99) STAUFFER CHEMICAL CO.
1964. WEED CONTROL IN RICE IN CALIFORNIA. 24 pp.

(100) STEVENS, J. D. H.
1962. MISSISSIPPI GROWERS REPORT PROGRESS. Rice Jour. 65(10): 21–24, illus.

(101) TAKEMATSU, T., and YANAGISHIMA, S.
1963. STUDIES ON THE HERBICIDAL PHENOMENON AND THE FUNCTION OF DICHLOROPROPIONANILIDE A WEED KILLER HAVING A SELECTIVE HERBICIDAL EFFECT ON GENERA OF GRAMINEAE. Il Riso (12(3): 37–70, illus.

(102) U.S. AGRICULTURAL RESEARCH SERVICE.
1962. ESTIMATED LOSSES CAUSED BY WEEDS IN AGRONOMIC CROPS—AVERAGES, 1951-1960. U.S. Agr. Res. Serv., Crops Res. Div., May, 1 p.

(103) ———
1962. SUMMARY OF REGISTERED AGRICULTURAL PESTICIDE CHEMICAL USES. U.S. Agr. Res. Serv., Pesticides Regulat. Div., Washington, D. C., 686 pp.

(104) VELASCO, J. R., VEGA, M. R., and LLENA, P. A.
1958. EFFECTS OF REPEATED HERBICIDE SPRAYING ON UPLAND RICE. Philippine Agr. 41(8): 432–439.

(105) VISTE, K. L.
1963. CONTROL OF WEEDS IN RICE IN CALIFORNIA. Rice Tech. Working Group Proc., Feb. 1962, Houston, Tex., pp. 10–11.

(106) VISTE, K. L. and FINFROCK, D. C.
1958. FACTORS INFLUENCING HERBICIDAL INJURY TO RICE. Rice Tech. Working Group Proc. 8: 9–12, illus.

(107) WARD, J. C.
1960. REGISTRATION OF HERBICIDES—STATUS, PROBLEMS, PLANS. Weed Soc. Amer. Spec. Panel Discuss. on Prog. and Prob. in Registering and Recommending Herbicides, pp. 6–10.

(108) WELLHAUSEN, H. W.
1955. RICE PRODUCTION IN ARKANSAS. Ark. Agr. Ext. Serv. Cir. 476, 12 pp., illus.

(109) WELLS, J. P.
1963. RICE FERTILITY RESEARCH IN ARKANSAS. Rice Tech. Working Group Proc., Feb. 1962, 10:9.

(110) WILLIAMS, R. E.
1955 and 1956. WEEDS IN RICE. Rice Jour. 58 (13): 18–19; 59(1): 8–9; (2): 8; (3): 8–9; (4): 14; (5): 24; (6): 34–35; (8): 22–23; (9): 15; (10): 16–17; (12): 20–28.

(111) WOOTEN, O. B., and HOLSTUN, J. T., JR.
1959. SPECIAL EQUIPMENT FOR CHEMICAL WEED CONTROL. Miss. Agr. Expt. Sta. Bul. 576, 16 pp., illus.

APPENDIX

TABLE 22.—*Common and chemical names of herbicides reported in handbook*

Common name	Chemical name
amitrole	3-amino-1,2,4-triazole
amitrole-T	3-amino-1,2,4-triazole-ammonium thiocyanate mixture
CIPC	isopropyl *N*-(3-chlorophenyl)carbamate
dalapon	2,2-dichloropropionic acid
EPTC	ethyl *N,N*-di-propylthiolcarbamate
MCPA	2-methyl-4-chlorophenoxyacetic acid
molinate	*S*-ethyl hexahydro-1 *H*-azepine-1-carbothioate
propanil	3′,4′-dichloropropionanilide
silvex	2-(2,4,5-trichlorophenoxy)propionic acid
swep	methyl 3,4-dichlorocarbanilate
2,4-D	2,4-dichlorophenoxyacetic acid
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
--------------	4-chlorobenzenesulfono-2-toluidide

ADDENDUM

Molinate has been cleared by the U.S. Department of Agriculture for controlling weeds in rice. It may be applied at 3 pounds per acre as a preplanting application on water-seeded rice, but may not be applied to dry-seeded rice. It is effective in controlling grass weeds when it is incorporated into the soil before flooding and seeding rice.

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