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RICE IN THE UNITED STATES: VARIETIES AND PRODUCTION

Agriculture Handbook No. 289

Agricultural Research Service

U.S. DEPARTMENT OF AGRICULTURE

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RICE IN THE UNITED STATES: VARIETIES AND PRODUCTION

INTRODUCTION

By C. ROY ADAIR

Rice, a leading cereal crop in many countries, is grown on all continents. It often is considered to be a tropical crop, although it is grown in both the temperate and the tropical zones in Africa, Asia, North America, Oceania, and South America, and in the southern part of Europe. About 93 percent of the world rice crop was produced in Asia during the 5-year period ending in 1960 (table 1). Only slightly more than 1 percent was produced in the United States during this period. The United States is, however, the leading rice-producing country in North America and is sec-

ond to Brazil in the Western Hemisphere. Other leading rice-producing countries, outside of Asia and adjacent islands, are United Arab Republic (Egypt) and Malagasy Republic (Madagascar) in Africa, and Italy and Spain in Europe.

Rice yields vary widely among the rice-producing countries (table 1). Yields generally are much higher in temperate than in tropical zones, not only because of differences in climate but also because of differences in cultural practices and in varieties grown.

TABLE 1.—*Rice acreage, production, and yield per acre for each continent and selected countries, averages for 5-year period, 1956–60*

Continent and country	Acreage	Production	Yield
	<i>1,000 acres</i>	<i>Million pounds</i>	<i>Pounds per acre</i>
Asia	258,000.4	427,330.2	1,656
India	81,353.2	99,106.7	1,218
Japan	8,050.2	32,845.4	4,081
South America	8,091.6	12,496.2	1,544
Brazil	6,615.0	9,539.7	1,442
Peru	166.4	574.4	3,452
Africa	7,808.0	9,686.0	1,240
Congo	400.0	392.6	982
United Arab Republic (Egypt)	695.4	2,832.4	4,073
North America	2,825.0	6,985.3	2,473
Mexico	315.6	582.0	1,844
United States	1,501.8	4,946.2	3,294
Europe	860.6	3,434.8	3,991
Italy	325.6	1,440.3	4,423
Spain	157.6	841.7	5,341
Oceania	117.2	330.9	2,823
Australia	50.2	240.7	4,795
World total	277,702.8	460,263.4	1,657

Source: U.S. Department of Agriculture, Agricultural Statistics: 1958, p. 21; 1959, p. 22; 1960, p. 22; 1961, p. 22.

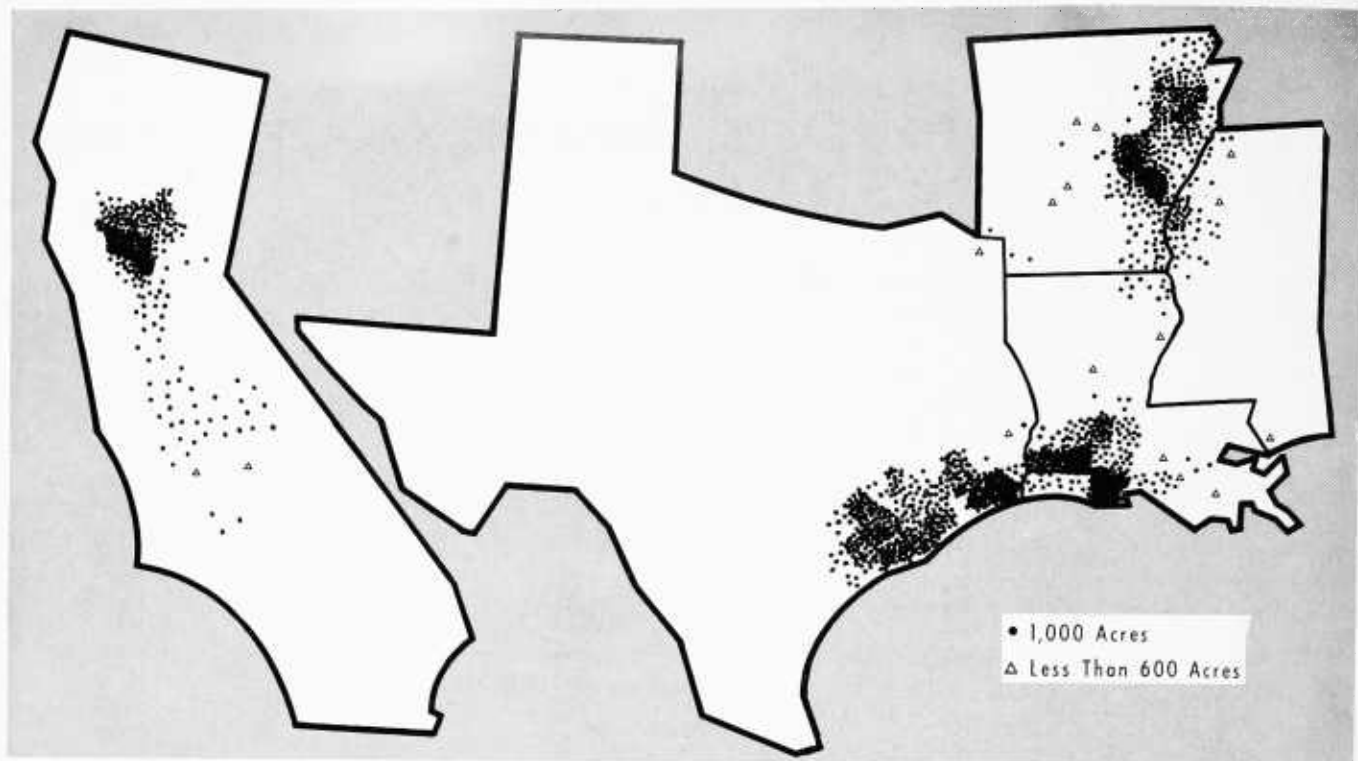
History of Rice in the United States

Rice has been grown in the United States since the latter part of the 17th century (2).¹ Trial plantings of rice were made in Virginia as early as 1609 (4). Apparently other plantings were made in the colonies along the South Atlantic coast from that time on, and ricegrowing was firmly established in South Carolina about 1690.

Until about 1890, rice in the United States was grown principally in the Southeastern States, although some was grown along rivers in the South Central States. Experimental plantings were

made in the prairie section of southwest Louisiana from 1884 to 1886 (7), and rice culture became established in that area about 1888. Production then increased rapidly in that part of Louisiana, and in the adjacent part of Texas. Some rice was grown along rivers in Arkansas in early years, but it did not become an important cash crop in the State until after 1904 (9), when ricegrowing was started in Grand Prairie. Experimental plantings were made near Butte Creek in the Sacramento Valley in California in 1909 (3), and rice became established as a commercial crop in that area about 1912. Rice production has been of considerable importance in the delta area of Mississippi since about 1948 (2).

¹ Italic numbers in parentheses refer to Selected References, p. 4.

**ARKANSAS**

SECTION AND COUNTY	ACRES
NORTHEAST	
Cloy	7,770
Craighead	16,935
Crittenden	6,439
Cross	34,060
Faulkner	318
Greene	5,406
Independence	852
Jackson	20,200
Lawrence	8,251
Mississippi	1,505
Poinsett	38,400
Randolph	2,100
St. Francis	17,840
White	1,140
Woodruff	19,760

CENTRAL

Arkansas	76,150
Clark	400
Conway	114
Hot Spring	470
Jefferson	17,046
Lee	8,395
Lanoke	39,000
Monroe	14,000
Perry	981
Phillips	5,068
Proirie	39,570
Puloski	1,855

SOUTHEAST

Ashley	6,429
Chicot	9,603
Desho	14,000
Drew	4,594
Lincoln	9,410

ARKANSAS CONT.

SOUTHWEST	
Lafayette	} ... 2,000
Little River	
Miller	
TOTAL ACRES.....	430,061
ARKANSAS 1963	

TEXAS

SECTION AND COUNTY	ACRES
EAST	
Bowie	559
Chambers	43,503
Hordin	1,004
Jasper	86
Jefferson	62,294
Liberty	37,540
Newton	731
Orange	4,972

CENTRAL

Brozorio	54,003
Ft. Bend	19,203
Golveston	12,143
Horris	34,889
Waller	15,038

WEST

Austin	2,865
Colhoun	4,287
Colorado	35,599
Jackson	27,153
Lovoca	6,194
Matagorda	44,846
Victorio	5,083
Whorton	52,740

TOTAL ACRES
TEXAS 1963 464,732

CALIFORNIA

SECTION AND COUNTY	ACRES
SACRAMENTO VALLEY	
Butte	55,202
Colusa	74,125
Glenn	40,846
Placer	3,050
Sacramento	10,126
Sutter	57,789
Yolo	25,062
Yuba	12,549

SAN JOAQUIN VALLEY

Fresno	20,818
Kern	3,435
Kings	197
Madera	2,745
Merced	7,429
San Joaquin	7,453
Stonislous	2,260
Tulare	544

TOTAL ACRES 323,630
CALIFORNIA 1963

MISSISSIPPI

COUNTY	ACRES
Bolivar	21,400
Coahoma	1,664
De Soto	1,639
Hancock	184
Humphreys	1,935
Leflore	3,874
Quitman	1,408
Shorkey	1,150
Sunflower	4,300
Talohatche	510
Tate	246
Tunica	2,895
Washington	9,427
TOTAL ACRES	50,632
MISSISSIPPI 1963	

LOUISIANA

SECTION AND PARISH	ACRES
NORTH	
East Carroll	5,267
Grant	185
Madison	896
Morehouse	5,949
West Carroll	1,185

RIVER

Ascension	1,316
Assumption	196
Iberville	323
Lafourche	54
St. James	1,472
St. John	1,436
Tensas	126

TECHE

Avoyelles	2,770
Iberio	6,500
Lafayette	9,530
Rapides	574
St. Martin	4,060
St. Mary	3,100

SOUTHWEST

Acadia	93,500
Allen	24,000
Beauregard	4,943
Calcasieu	65,088
Cameron	13,337
Evangeline	39,640
Jefferson Davis	95,692
St. Landry	16,945
Vermillion	114,800

TOTAL ACRES 512,884
LOUISIANA 1963

FIGURE 1.—Distribution of the United States rice acreage in the principal producing States.

Distribution of Rice in the United States

Although rice is probably the leading food crop of the world, it is a major crop in the United States in certain areas only. Rice production in the United States is centered in the Southern States of Arkansas, Louisiana, Mississippi, and Texas and in California. It is the principal cash crop in many counties and parishes (fig. 1). Small amounts of rice also are grown in Missouri, Oklahoma, South Carolina, and Tennessee. Some rice has been grown in each of the States in Southeastern United States.

In the United States, satisfactory rice crops require (1) high temperature, especially relatively high mean temperatures during the growing season; (2) a dependable supply of fresh water for irrigation; (3) a terrain that is level enough to permit flood irrigation but that slopes enough so that surface water can be readily drained; and (4) soil that will hold water well because of its fine texture, or a subsoil through which loss by seepage is small (6). These climatic and soil conditions prevail in the areas where rice is grown in the United States.

Rainfall and humidity during the growing season are comparatively high in the Southern States, so less irrigation water is required there than in California (1). Irrigation water is supplied from streams, from reservoirs where water is impounded in winter and early spring, and from wells. To produce optimum yields, proper cultural practices must be followed. These practices include preparing a suitable seedbed, maintaining a uniform depth of irrigation water, providing sufficient soil nutrients for optimum growth, and controlling insects and diseases and weeds and grasses. Good-quality seed of adapted varieties must be used to maintain quality and to produce high economical yields. For safe storage, the rice must be harvested at the right stage and dried to the proper moisture level.

Acreage, Yield, and Production of Rice in the United States

In the 5-year period ending in 1963, Arkansas produced 24.89 percent of the total United States rice crop; Louisiana, 24.26 percent; California, 24.12 percent; Texas, 23.99 percent; Mississippi, 2.47 percent; and Missouri, 0.26 percent (8). The United States has been self-sufficient in rice production since 1917, and now is one of the leading rice-exporting countries of the world.

Rice acreage in the United States (fig. 2) increased from a 5-year annual moving average of 301,000 acres in 1899 to 1,105,000 acres in 1922. It then declined until 1936. The 5-year annual

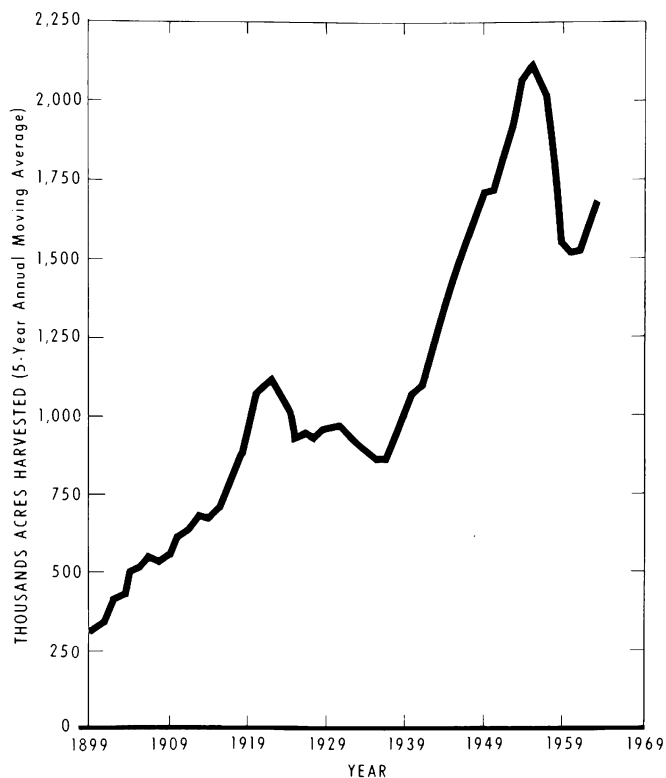


FIGURE 2.—Harvested acreage of rice in the United States (5-year annual moving average), 1899-1963.

moving average acreage increased each year until 1955, when it was 2,106,000. The peak acreage of 2,550,000 was reached in 1954. The annual acreage then declined until 1957, when it was 1,340,000. Starting in 1958, acreage increased slightly each year until 1963, when it was 1,765,000.

Yield per acre (fig. 3) in the United States increased from a 5-year annual moving average of 1,091 pounds per acre in 1899 to 3,563 pounds per acre in 1963. This gradual increase in yield per acre has been brought about by improved cultural practices, such as better rotations, weed control, and irrigation and fertilization practices; better machinery, which led to improved and more timely field operations; better methods of controlling diseases and insects; and improved varieties. Average yields have fluctuated from year to year, with a long-term upward trend. However, there have been short periods when average yields declined. The 5-year annual moving average yield per acre increased gradually from 1899 to 1940, but six times during this period the 5-year average yield was lower than that of the previous year. Yields declined from 1941 to 1945. Labor and equipment were scarce during the war years, and the acreage was expanded to include some

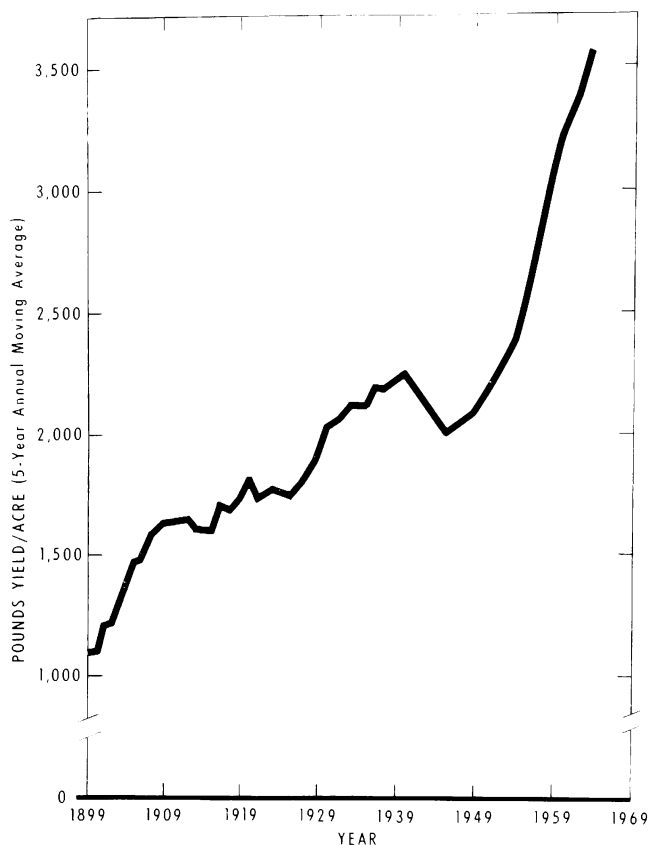


FIGURE 3.—Yield per acre of rice in the United States (5-year annual moving average), 1899–1963.

fields with poor soil. These factors may have accounted for the lower yields in this period. The 5-year average yield per acre increased each year from 1946 through 1963. Higher rates of fertilizer application and other improved cultural practices increased yields during this period.

Production of rice (100-pound bags) in the United States in 1718 was estimated to be over 79,000 bags of rough rice (5). Production increased to nearly 3.5 million bags in 1849. It then declined to about 637,000 bags by 1871. By 1899, production had increased to 3.4 million bags.

The 5-year annual production increased to 19.4 million bags in 1922. Production declined until 1926 and then increased slightly. However, it remained within the range of 14 to 20 million bags until 1936. The annual production fluctuated from year to year but with an upward trend during the period from 1937 to 1954 when production reached a high of 64.2 million bags. Annual production declined until 1958 and then increased each year until 1963 when the annual

production was 69.3 million bags, and the 5-year annual moving average was 59.3 million bags (fig. 4).

Selected References

- (1) ADAIR, C. R., and ENGLER, KYLE.
1955. THE IRRIGATION AND CULTURE OF RICE. *In* Water, U.S. Dept. Agr. Yearbook of Agr., pp. 389–394.
- (2) ———, MILLER, M. D., and BEACHELL, H. M.
1962. RICE IMPROVEMENT AND CULTURE IN THE UNITED STATES. *Adv. in Agron.* 14: 61–108.
- (3) CHAMBLISS, C. E.
1912. A PRELIMINARY REPORT ON RICE GROWING IN THE SACRAMENTO VALLEY. U.S. Dept. Agr., Bur. Plant Indus. Cir. 97, 10 pp.
- (4) GRAY, L. C., and THOMPSON, E. K.
1941. HISTORY OF AGRICULTURE IN THE SOUTHERN U.S. TO 1860. Carnegie Inst. Wash. Pub. 430. [Reprinted in 2 v.] Peter Smith, New York.
- (5) HOLMES, G. K.
1912. RICE CROP OF THE UNITED STATES, 1712–1911. U.S. Dept. Agr., Bur. Statis. Cir. 34, 11 pp.
- (6) JONES, J. W., 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.
- (7) KNAPP, S. A.
1899. THE PRESENT STATUS OF RICE CULTURE IN THE UNITED STATES. U.S. Dept. Agr., Bot. Div. Bul. 22, 56 pp.
- (8) UNITED STATES DEPARTMENT OF AGRICULTURE.
1963. RICE. ANNUAL MARKET SUMMARY, 1963. U.S. Agr. Market. Serv. AMS-277, 47 pp.
- (9) VINCENHELLER, W. G.
1906. RICE GROWING IN ARKANSAS. Ark. Agr. Expt. Sta. Bul. 89, pp. 119–129.

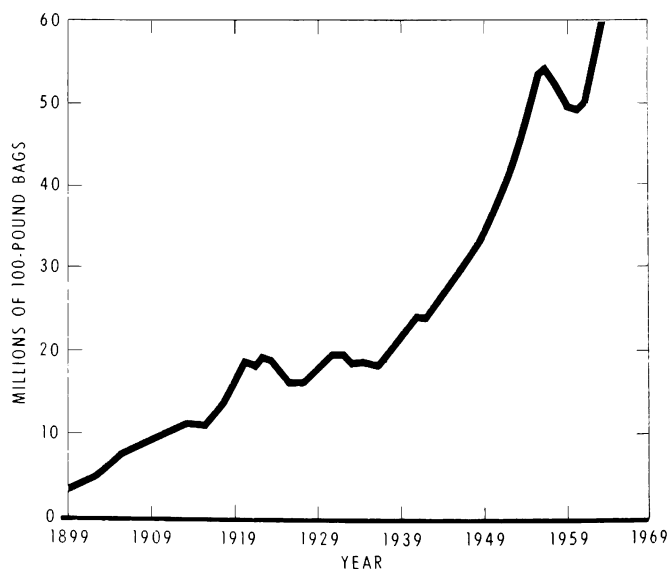


FIGURE 4.—Production of rice in the United States (5-year annual moving average), 1899–1963.

DISTRIBUTION AND ORIGIN OF SPECIES, BOTANY, AND GENETICS

By C. ROY ADAIR and NELSON E. JODON

Distribution of the Species of *Oryza* and Origin of Cultivated Rice

Species of *Oryza* have been reported from all continents except Europe and from many of the larger islands. Roschevicz (53) ¹ reported a comprehensive study of the genus, and he concluded from his study that there were 20 species of *Oryza*. Chevalier (15) reported a similar study in which he recognized 22 species. Chatterjee (13) later summarized the information on *Oryza* and listed 23 species. Tateoka (64) summarized the information on species of *Oryza* in 1963 and recognized 22 valid species. The 18 species that were recognized by both Chatterjee (13) and

Tateoka (64) are listed in table 2.

Five species were recognized by Chatterjee (13) but not by Tateoka (64) so they were not listed in table 2. These are *O. granulata* Nees & Arn. ex Hook. f.; *O. perennis* Moench; *O. sativa* L. var. *fatua* Prain; *O. stapfi* Roschev.; and *O. subulata* Nees. Four species were recognized by Tateoka (64) but not by Chatterjee (13) so they were not listed in table 2. These are *O. angustifolia* Hubbard; *O. barthii* A. Cheval.; *O. longiglumis* Jansen; and *O. rufipogon* Griff. The chromosome number of the species of *Oryza* as reported by Kihara (35) and the distribution as reported by Chatterjee (14) also are shown in table 2.

TABLE 2.—Species, chromosome number, and distribution of *Oryza*

Species	Chromosome No. (2n)	Distribution
1. <i>O. alta</i> Swallen	24 and 48	South America and Central America.
2. <i>O. australiensis</i> Domin	24	Australia.
3. <i>O. brachyantha</i> A. Cheval. & Roehr.	24	West Tropical Africa and Central Africa.
4. <i>O. breviligulata</i> A. Cheval. & Roehr.	24	West Tropical Africa.
5. <i>O. coarctata</i> Roxb.	48	India and Burma.
6. <i>O. eichingcri</i> Peter	48	East Africa.
7. <i>O. glaberrima</i> Steud.	24	West Tropical Africa and Central America. ¹
8. <i>O. grandiglumis</i> (Doell) Prodoehl	24 and 48	South America.
9. <i>O. latifolia</i> Desv.	48	Central America, South America, and West Indies.
10. <i>O. meyeriana</i> (Zoll. & Mor.) Baill.	24	Java, Borneo, Philippines, and Siam.
11. <i>O. minuta</i> Presl	48	Malay Peninsula, Philippines, Sumatra, Java, and Borneo.
12. <i>O. officinalis</i> Wall. ex Watt	24	India and Burma.
13. <i>O. perrieri</i> A. Camus		Madagascar.
14. <i>O. punctata</i> Kotschy ex Steud.		Northeast Tropical Africa.
15. <i>O. ridleyi</i> Hook. f.	48	Malay Peninsula, Siam, Borneo, and New Guinea.
16. <i>O. sativa</i> L.	24 and 48	India and Indo-China.
17. <i>O. schlechteri</i> Pilger		New Guinea.
18. <i>O. tisseranti</i> A. Cheval.		Central Africa.

¹ P.I. 269630. Collected in El Salvador by H. M. Beachell and identified by Eugene Griffith, Crops Research Division, Agricultural Research Service, Beltsville, Md., and J. R. Swallen, Smithsonian Institution, Washington, D.C.

Roschevicz (53) divided the species of *Oryza* into four sections on the basis of morphologic characters and geographic distribution. Kihara (35) modified this grouping to include species not reported by Roschevicz.

In 1963, a committee ² reviewed the classifica-

¹ Italic numbers in parentheses refer to Selected References, p. 16.

² This committee was appointed at the Rice Genetic Symposium convened at the International Rice Research Institute, Los Banos, the Philippines. The members were S. Sampath, India; T. Tateoka, Japan; and M. T. Henderson, United States.

tion and nomenclature of *Oryza* and recommended that standards be adopted and used uniformly. This committee recognized 19 valid species of *Oryza*. Seventeen of these species are listed in table 2. The species not recognized by this committee that is listed in table 2 is *O. grandiglumis*. The other two species recognized by this committee are *O. angustifolia* and *O. longiglumis*. The committee also believed that certain aspects of taxonomy in *Oryza* are uncertain. These are: (1) The relation and nomenclature among the taxa commonly designated as *O. sativa* var. *fatua*

(or *f. spontanea* Roschev.) and *O. perennis* (Asiatic, American, and African) subspecies and varieties; (2) the relation of the form commonly designated *O. stapfi* to *O. glaberrima* and *O. breviligulata*; (3) the relation between *O. granulata* f. and *O. meyeriana*; (4) the relation between *O. alta* and *O. grandiglumis*; and (5) the status of the taxa previously designated *O. ubanghensis* Chev. and *O. malampuzhaensis* Krish. and Chand. The committee also believed that the form commonly designated *O. subulata* should be excluded from *Oryza* and should be recognized as *Rhynchoryza subulata* (Nees) Baill.

Chatterjee (14) reviewed the literature on the origin and distribution of wild and cultivated rice. He concluded that the eastern part of India, Indo-China, and part of China could be considered the area where cultivated rice (*Oryza sativa*) originated. Chatterjee further concluded, as did Roschevich (53), that for the genus as a whole or the section *Sativa* Roschev., the center of origin is Africa. He was of the opinion that *O. alta*, *O. australiensis*, *O. brachyantha*, *O. eichingeri*, *O. grandiglumis*, *O. latifolia*, *O. minuta*, *O. perrieri*, *O. schlechteri*, *O. subulata*, and *O. tisseranti* had little part in the ancestry of cultivated rice. This view seems to be based either on the fact that these species do not cross with *O. sativa* or on the fact that they occur naturally in areas far removed from the center where rice cultivation originated.

Many investigators have studied and discussed the origin of the genus *Oryza* and of cultivated rice (13, 14, 15, 35, 46, 48, 50, 53, 55, 56, 67, 70). It is generally concluded that the original ancestral species may no longer exist and that present varieties evolved through progressive stages from known wild species (56).

Nandi (44) and Sakai (54) proposed that a species with a haploid number of five chromosomes was the ancestor of *Oryza*. This proposal was rather widely accepted. Nandi (44) observed that in the somatic complement having 24 chromosomes there were two members of eight types and four members of two types. The maximum association in second metaphase was two groups of three and three groups of two. It was concluded from this observation that the haploid genome of the present *O. sativa* is composed of two original five-paired species belonging to two different ancestral genomes in which two chromosomes were duplicated.

Later, Shastri, Rao, and Misra (60) identified 12 pachytine bivalents in a strain of *O. sativa*, based on their length and arm ratios. This finding seems to cast considerable doubt on the validity of the supposition "that *O. sativa* is a secondarily balanced allo-tetraploid which originated through hybridization between two different five-paired species in which two chromosomes

were duplicated, probably due to meiotic irregularities in the hybrid. This followed by a subsequent doubling of the chromosomes attained the secondary balance of $n=12$, the present existing number of *O. sativa*" (44).

Sampath and Rao (56) "inferred that *Oryza perennis* is the ancestral form of cultivated rices, having given rise to *O. sativa* in Asia and *O. glaberrima* in Africa by human selection." These authors were of the opinion that *O. breviligulata* and *O. sativa* var. *fatua* are of collateral descent from *O. perennis*. The present types that are classified as *O. sativa* var. *fatua* or *spontanea* show morphologic differences that may be due to genetic transfer from cultivated rice. From this it is inferred that these wild forms are derived from hybrids with cultivated rices and are not the progenitors of cultivated rice. Instead it has been strongly suggested (55, 56, 70) that an intermediate type may be the immediate ancestor of *O. sativa*.

Description and Development of the Rice Plant and Classification of Cultivated Varieties

Cultivated varieties of *O. sativa* are divided into groups on the basis of several characters. The principal division is on the basis of sterility of the hybrid. Kato and others (33, 34) observed that in crosses of certain varieties from the temperate zone and certain varieties from tropical areas, the hybrids had a high percentage of sterile florets. The hybrids between varieties within these two groups were as fertile as self-pollinated parent varieties.

They proposed that the temperate zone varieties be named japonica and the tropical zone varieties indica. Kato and others (34) observed no difference between japonica and indica varieties in chromosome number and behavior or in pollen formation. However, in the hybrid, pollen formation was abnormal. Serological investigations showed differences between japonica and indica varieties.

Later, Terao and Midusima (66) noted that another group of varieties, principally from tropical islands of Southeast Asia, were intermediate. This last group is referred to as bulu.

It appeared from the earlier studies that the varieties could be divided into three distinct groups based on sexual affinity. Mizushima (39), however, determined that this was not true and that sexual affinities among varieties from these groups varied gradually from one extreme to the other.

Oka (45) compared 147 varieties from widely different geographic areas on the basis of a number of morphologic and physiologic characters

and by observing sexual affinity in hybrids. From these studies, he placed the 147 varieties tested into indica (continental) and japonica (insular). He subdivided the japonica group into "tropical-insular" and "temperate-insular."

In a review on reports of sterility in hybrids between indica and japonica varieties, Shastri, Rao, and Misra (60) explained sterility on the

basis of chromosome structural differences, lethal genes, inversions, paracentric inversions, genic mutations, and cryptic structural hybridity.

There are many morphologic differences between typical japonica, indica, and bulu varieties (table 3). Varieties that are known to be progenies of hybrids are intermediate in many respects.

TABLE 3.—*Characters of japonica, indica, and bulu rice varieties*

Character	Japonica	Indica	Bulu
Grain shape	Short	Long	Large.
Second foliar leaf:			
Length	Short	Long	Long.
Angle	Small	Large	Small.
Foliage color	Dark green	Light green	Light green.
Culm:			
Stiffness	Stiff	Not stiff	Stiff.
Erectness	Upright	Spreading	Upright.
Length	Short	Long	Long.
Flag leaf:			
Angle	Medium	Upright	Medium.
Shape	Narrow and short	Narrow and long	Broad and long.
Degree of emergence of upper node.	Medium	Well emerged	Not emerged.
Number of tillers	Many	Many	Few.
Pubescence	Pubescent	Variable	Variable.
Awns	None	None	Many.
Panicles:			
Number	Many	Many	Few.
Weight	Heavy	Light	Heavy.
Length	Short	Long	Medium.
Density	Dense	Medium	Medium.
Branching of rachis	Few	Medium	Many.

Source: Nagai (40).

Description of plant

The principal parts of the rice plant are a fibrous root system, culms, leaves, and panicles.

The fibrous root system extends outward and downward from the base of the plant. Adventitious roots that arise from the lower nodes of the culms are finely branched. The extent of the root system and the size of the roots vary with variety and type of culture.

The culm and leaves develop from the plumule. The culm consists of the nodes, which have solid centers (septum), and the internodes, which are hollow. The culms of most varieties of *Oryza sativa* are erect or ascending, although there are procumbent types. Varieties range in height from less than 15 to more than 96 inches (37 to 240 centimeters) although varieties grown in the United States range from 36 to 54 inches. The culms vary in diameter at the base from 5 to 15 millimeters. The number of nodes in the culm ranges from 13 to 16 (32), and the number is significantly correlated with length of growing season. Usually, four internodes elongate; the upper internode (peduncle) is usually the longest, and it bears the panicle.

The leaves of the rice plant are flat and range from 7 to 20 millimeters wide. The coleoptile usually is considered to be the first leaf. It has stomata but few chloroplasts. The mature foliage leaf consists of the sheath at the base, which surrounds the culm for some distance; the blade, which is set at an angle with the sheath; the ligule; and the auricles. The junction of the sheath and blade often is called the collar or junctura. The swollen zone at the base of the sheath where it joins the culm is the pulvinus.

The panicle of most varieties is fairly dense and drooping. There is, however, much intervarietal variation, since the panicle ranges from open to very compact and from erect to drooping. From one to three or sometimes more branches arise alternately or somewhat in whorls at each node of the peduncle. The rachilla bears the spikelet, and each rachilla arises on the same side of the rachis. Each rachilla usually has a single spikelet, although some varieties may have two or more spikelets on a rachilla. The spikelet is laterally compressed, is one flowered, and articulates below the outer glume.

The two outer glumes usually are short, that is, less than one-third the length of the lemma, al-

though there are types that have glumes as long as the lemma or longer. The lemma (inferior or lower flowering glume) is rigid, keeled, and three nerved, and has two additional thin, marginal nerves that can be seen only in section. The apiculus or tip of the lemma is sometimes prolonged to form the awn. The palea (superior or upper flowering glume) is similar to the lemma, but narrower. It has two nerves near the margin and a thin midnerve that can be seen only in section. The flower is composed of a one-carpellate pistil with a bifurcated, plumose slender style; and six stamens with yellowish, four-lobed, two-celled anthers. The principal parts of the caryopsis (brown rice) are the embryo and endosperm and the covering tissues.

Development of plant

Rice seed germinates rapidly when moisture, temperature, and oxygen are optimum. The embryo, which consists of the organs that develop to produce the rice plant, lies in a slanting position at the base of the grain on one side of the endosperm. The endosperm contains the stored food that nourishes the developing seedling until the roots have developed sufficiently to obtain nutrients from the soil.

At germination, the coleorhiza pushes through the pericarp, leaving a cavity. The primary root soon elongates, fills the cavity, and then pushes through the coleorhiza. The root extends upward for a short distance and then turns down. About this same time, the coleoptile emerges and rapidly elongates. The epicotyl below the coleoptile also elongates. Elongation varies with the depth the seed is planted. It elongates enough to bring the base of the coleoptile to the surface of the soil. When the coleoptile emerges from the soil, it splits on the side opposite the scutellum, and the foliage leaves soon appear. Usually in about 2 days, two adventitious roots start to develop in the meristematic zone on the side opposite the scutellum. A third adventitious root may appear later at the coleoptile divergence opposite the two older ones. Lateral roots soon develop from the primary and adventitious roots (71).

The main axis of the plant, often called the primary tiller, is differentiated rapidly. The meristematic region is at the base of the internodes; this is typical of all grasses. With three early (130-day) United States varieties, tillering started within 3 weeks after germination, and all tillers that produced panicles were formed within a 3-week period (4). Japonica varieties started to tiller about 14 days after transplanting and tillering was completed in 23 to 25 days (32). Indica varieties started to tiller about 14 days after transplanting, and all tillers were initiated in 3 to 5 weeks from this time, depending on the

length of growing period of the variety (49). Tillers develop from buds in the axil of the node and the arrangement is alternate (32, 49). Japonica varieties (32) develop secondary tillers from the buds at nodes 3 or 4 to 10. Tillers from node 10 often do not produce panicles. Tertiary tillers may develop from buds at nodes of the secondary tillers.

Panicle formation starts when all nodes have been formed. The length of the period from seeding or transplanting to the starting of panicle formation varies with the length of growing period of the variety. The period up to formation of the panicle primordium constitutes the "vegetative" stage. It is this period that accounts for the variation in length of growing period among varieties. Formation of the panicle primordium starts about 50 days after seeding for very early United States varieties and about 100 days for later United States varieties. The period from formation of the panicle primordium to emergence of the panicle from the sheath ranges from 24 to 31 days for indica varieties (49) and from 28 to 36 days for japonica varieties (5).

For indica varieties, the panicle primordium can be noted when it is 0.125 to 0.25 millimeters long. By the time it is 0.5 millimeters long, "hemispherical excrescences are observed at the base" (49). The hemispherical excrescences represent the branches of the panicle. Rudiments of the spikelet on either side of the basal axis are perceptible when the panicle primordium is 5.0 millimeters long. The panicle primordium then elongates, and the spikelets are differentiated progressively from the tip down to the base of the panicle. Spikelets in the tip and middle of the panicle have reached maximum length by the time the panicle has completed its elongation, which is 15 to 20 days after formation of panicle primordium. The spikelets at the base of the panicle complete their elongation by the time the panicle emerges from the sheath (49).

Similar results were reported for a variety from the Philippines (30). Anthesis starts the first day of emergence of the panicle. It begins with the flowers at the tip of the panicle and continues progressively at the tip of each branch of the panicle. The greatest number of flowers open the second or third day after the panicle emerges. Anthesis occurs over a period of 6 to 10 days, varying with weather and variety. It usually occurs from midmorning to shortly after noon. The time differs with variety, location, and weather (3, 52). Pollen is shed just before or at the time the flower opens.

The formation and development of the embryo of a japonica variety (65) and of a variety from the Philippines (30) has been described. The process is similar in both varieties. Juliano and Aldama (30) reported that "development of the

megasporange, megaspore mother cell, and embryo is normal and follows very closely those reported by other investigators. The embryo sac is of the normal octonucleate type." These investigators also observed that "development of the microsporangium is normal and follows those reported in many angiosperms"; that "division of the microspore mother cell is successive"; and that "long before anthesis the young microspore contains two coats, a thin peripheral cytoplasm, wherein a single nucleus is embedded, and a single germ pore." Double fertilization occurs about 12 hours after anthesis (65). In a japonica variety, the caryopses reach maximum length in about 12 days after flowering, maximum width or breadth (dorsoventral diameter) in about 22 days, maximum thickness (lateral diameter) in about 28 days, and maximum dry weight in about 35 days (37). Similar results were obtained for United States varieties; air-dry kernel weight and percentage of germination were maximum about 35 days after the first panicles emerged from the sheath (61).

Classification of varieties

Cultivated varieties of rice belong to the genus *Oryza* L., tribe Oryzeae, and family Gramineae. Most cultivated varieties are in the species *Oryza sativa* L., although varieties of the species *O. glaberrima* are cultivated in Africa. *O. sativa* is an annual; but when moisture and temperature are optimum and in the absence of disease, plants have survived and produced grain for 20 years or more.

All varieties of rice grown in the United States are in the species *O. sativa* L. The commercial varieties are classified on the basis of (1) length of growing season, (2) size and shape of the grain, and (3) chemical character of the endosperm. Ito and Akihama (22) further classified varieties on the basis of plant height, straw strength, disease resistance, and color of various plant parts.

On the basis of length of growing season, United States varieties grown in the Southern States are divided into four groups: (1) Very early (100–115 days); (2) early (116–130 days); (3) midseason (131–155 days); and (4) late (156 days or more). The length of growing season is somewhat longer in California than in the South. The difference in length of growing season between these two areas is caused by day length and temperature.

The United States varieties are divided into three grain size and shape classes: short (Pearl), medium, and long. The more slender long-grain varieties sometimes are considered a fourth class. Examples of the respective groups are Caloro, Nato, Bluebonnet 50, and Rexoro. (See "Rice

Breeding and Testing Methods in the United States," p. 31.)

On the basis of chemical characters, rice types are divided into waxy (glutinous; endosperm contains no amylose) and common (ordinary starchy; endosperm contains amylose as well as amylopectin). Only a very small acreage of waxy rice is grown in the United States. The percentage of amylose in the starch in the endosperm of varieties grown in the United States varies rather widely. ("See Rice Breeding and Testing Methods in the United States," p. 38.)

A more detailed system is needed to classify the many varieties and lines used in breeding studies. Much work has been done to devise objective methods of classifying rice varieties. Previous work was summarized and a proposal for classifying rice varieties was formulated by a special committee in India (21). The committee proposed that rice varieties be classified on the basis of qualitative and quantitative characters. Nagai (40) reviewed systems used to classify rice varieties. These systems were followed rather closely in the Food and Agriculture Organization, "World Catalogue of Genetic Stocks—Rice," (1) and subsequent supplements. The classification system used in the United States includes the items in these systems with certain modification and additions.

Genetics

Varieties of ordinary cultivated rice, being largely self-pollinated, remain uniform and constant if care is taken to preserve pure seed. Mutations, chromosome changes, and natural crossing, however, have brought into existence a wide diversity of types and varieties that affect every part and function of the plant. Plants may be short or tall enough to grow in deep water; may have colored pigments of various shades distributed in different patterns over the plant; may tiller little or profusely; may have long and slender or short and round grains, with or without awns; and may have translucent or opaque kernels that differ in chemical composition. Also, the life cycle of one plant may be three times as long as that of another.

Differences that can be sorted into distinct contrasting classes make possible the study of segregation and recombination as well as linkage relationships of genes, which are the units of heredity. For convenience in publishing genetic studies, differences that have individual efforts great enough to be recognized are assigned gene symbols. To promote uniform usage among rice geneticists, the International Rice Commission of the Food and Agriculture Organization of the United Nations has adopted and recommended the gene symbols listed below (2).

Inherited differences, such as plant height, that are not clear cut but that grade from one extreme to another involve the interaction of several genes that have similar effects, but the actual number and the individual contribution of the genes involved remain uncertain.

Gene symbols adopted and recommended for rice¹

A	A, A ^d , a	= allelic anthocyanin activator genes (complementary action with C genes produces red or purple in apiculus)
	al	= albino ²
	An	= Awned ²
	au	= rudimentary auricle
B	bc	= brittle culm
	Bd	= Beaked hull (tip of lemma recurved over palea)
	Bf	= Brown furrow (dark brown color in furrows of lemma and palea). See H ^r
	I-Bf	= Inhibitor of dark brown furrow
	bg	= coarse (big) culms
	Bh	= Blackhull (complementary genes) ²
C	bl	= physiologic diseases showing dark brown or blackish mottled discoloration of leaf
	bn	= bent node—culm forms angle at node
	C, C ^B , C ^{Bp} , C ^{Bc} , C ^{Bt} , e	= allelic basic genes for anthocyanin color; higher alleles have pleiotropic expression in internode
	C alone	= tawny colored apiculus
	CA	= red or purple colored apiculus
	CAP	= completely and fully purple colored apiculus
	En-C	= Enhancer of C
	Ce	= <i>Cercospora</i> resistance
	chl	= chlorina (chlorophyll deficiency)
	Cl	= Clustered spikelets, also super cluster
	cls	= cleistogamous spikelets
	clw	= claw-shaped spikelets. See tri and Bd
D	d	= dwarfs; ² about 1/3 to 1/2 height or normal; discrete classes in segregating populations
	da	= double awn
	Dn	= Dense or "compact"; very close arrangement of spikelets (vs. normal panicle); epistatic to Ur. See Lx, also Cl
	Dn ₂	= Dense vs. lax
	Dn ₃	= Normal vs. lax
	Dp	= Depressed palea and underdeveloped palea
	dw	= deep water paddy, so-called floating rice

E	Ef	= Early flowering (low photosensitivity). ² See Lf
	En-	= Enhancer (intensifier). Precedes symbol of character affected
	er	= erect growth habit, recessive to spreading or procumbent. See dw, la
	Ex	= Exerted vs. enclosed panicle
F	Fgr	= Fragrant flower
	fs	= fine stripe
G	g	= long glume ² exceeding 1/3 length of the spikelet
	gh	= goldhull (golden yellowhull, recessive to straw color.) See Wh
	gl	= glabrous (nonhairy) leaf. See Lh
	Gm	= semi-dominant long glume. More extreme and less regular in expression than g. Epistatic to g
		green and white stripe; see fs, v.
H		(H or h is suggested to denote hull, i.e., lemma and palea)
	H ^m , H ^l , H ^s , H ^r	= allelic genes for nonanthocyanin colors of lemma and palea appearing only in the presence of Gh; goldhull colors appear with gh
	He	= <i>Helminthosporium</i> resistance
	hsp	= hullspot
I	I	= positive vs. negative staining with iodine-potassium iodide solution
	I-	= inhibitor (precedes symbol of character inhibited)
K		(K or k is suggested to denote kernel, i.e., caryopsis)
L		(l as second letter of a symbol) is suggested to denote leaf.)
	l-	= lethal (precedes symbol of character having lethal effect)
	la	= lazy. See er
	Ld	= Lodging
	Lf	= Late flowering (highly photosensitive). ² See Ef
	lg	= liguleless (auricle and collar also absent) ²
	Lh	= very hairy (long hair) dominant to ordinary pubescence. See gl
	lk	= grain length (long grain) ²
	lmx	= extra lemma
	lu	= lutescent
M	Lx	= Lax vs. normal panicle. See Dn
	Lx ₂	= Lax vs. compact
	me	= multiple embryos (polyembryonic)
	mp	= multiple pistils (polycaryoptic)
N		mottled leaf; see bl
O	nal	= narrow leaf
	nl	= neckleaf
	nk or I-Nk	= notched kernel
P		
P		(P as first letter of a symbol) is suggested to denote anthocyanin color.)
		Exceptions: Ph, Pi
	P	= Completely purple apiculus (complementary action with C and A)
	Pau	= Purple auricle, basic to Plg
	Pg	= Purple outer glumes
Pi	Ph	= Phenol staining of hull and bran
	Pi	= <i>Piricularia</i> resistance

¹ Recommended by the Eighth (1959) FAO International Rice Commission Working Party on Rice Production and Protection; the list includes present revisions.

² More than one gene involved; subscripts to be supplied by workers as needed. Letter subscripts are suggested for complementary genes, numeral subscripts for genes having phenotypically similar effects and also for polymeric genes.

Pin	= Purple internode. See C
Pl	= Purple leaf. See Pw
Pla	= Purpleleaf apex (complementary action with C and A)
Plg	= Purple ligule. See Pau
I-P1	= colorless leaf except margin
Pn	= Purplenode
Pr	= Purplehull (lemma and palea) (complementary action with CAP)
Prp	= Purple pericarp
Ps	= Purple stigma (complementary action with CAP)
Psh	= Purple sheath
Pu	= Purple pulvinus
Pw	= Purplewash. See Pl
Px	= Purple axil
R	
Re	= Brown pericarp (basic to Rd)
Rd	= Red pericarp (complementary action with Re)
ri	= verticillate (whorled) arrangement of rachis ("rinshi" character)
Rk	= Round spikelet (kernel)
rl	= rolled leaf
S	
s	= sterility ²
Sc	= <i>Sclerotium oryzae</i> resistance
Se	= Photosensitivity. See Ef, also Lf
Sh	= Dominant shattering as in drop-seed or wild types vs. difficult or intermediate threshing. See th
Sk	= Scented kernel
sn	= sinuous neck. See Ur
spr	= spreading panicle branches
	spreading growth habit; see er, also la superclustered spikelets; see Cl
T	(T is suggested to denote plant height ("Tallness") except where controlled by dwarfing genes.) See d
I-T	= short nondwarf plant vs. tall
th	= tipburn yellow
Tf	= Tough dehulling
th	= shattering or easy threshing recessive to difficult separation. See Sh
tl	= twisted leaves
tri	= triangular hull (spikelet). See clw
U	
Ur	= Undulate rachis vs. normal. See sn
V	
v	= virescent, also green and white stripe. See fs
W	
wb	= white belly (endosperm)

wb ₂	= white core (endosperm)
Wh	= Whitehull, epistatic to gh
wx	= waxy (glutinous) endosperm
Y	
y	= yellow leaf
l-y	= lethal yellow, also xantha ²
Z	
z	= zebra stripe

Plant colors have been studied more extensively than other characters in rice because they are readily classified, and it is possible to analyze precisely the genic action and interaction. From the economic standpoint, colors are of limited importance. Red bran color usually is objectionable as a mixture in ordinary white rice; purple bran varieties are used locally for rice wine or special preparations; purple leaf varieties have been distributed for growing in red-rice infested areas, so that the weedy type may be identified in the seedling stage and pulled out.

The segregation and interaction of color genes in Japanese varieties have been analyzed thoroughly (62). Purple (anthocyanin) colors, if present, ordinarily are manifest at least in the apiculus. The gradations from dark purple to pink and colorless were found to be controlled by five allelic chromogen genes, C^B, C^{Bp}, C^{Bt}, C^{Br}, and c. However, C genes alone produce no color in the flowering stage but are responsible for brown colors in decreasing intensity, which appear as the spikelet matures.

Activator gene A also must be present to convert the basic color pigment to purple anthocyanin. There are three alleles at the A locus. A third gene P, present in all but a few varieties, brings out distinct coloration. The numerous colors produced in the apiculus by the interactions of the C and A alleles in the presence of P are shown in table 4.

The C^B allele in the presence of A and A^d also has pleiotropic effect, producing color in the internode. C alleles with A and also less distinctly with A^d result in colored outer glumes.

TABLE 4.—*Apiculus colors resulting from interaction of C and A alleles in the presence of the P gene in Japanese rice*

Activator alleles	C ^B	C ^{Bp}	C ^{Bt}	C ^{Br}	c	Color at time indicated
A -----	{Purple -----	Red purple ----	Red -----	Pink -----	Colorless ----	Flowering.
	{Purple -----	Red purple ----	Red -----	Colorless ----	do -----	Maturity.
A ^d -----	{Deep red -----	Red -----	Orange tinge --	Orange tinge --	do -----	Flowering.
	{Brown -----	Light brown --	Yellow tinge --	Colorless ----	do -----	Maturity.
a -----	{Colorless -----	Colorless -----	Colorless -----	Colorless -----	do -----	Flowering.
	{Dark brown ----	Brown -----	Light brown --	Yellow tinge --	do -----	Maturity.

Source: Takahashi (62).

Combinations of C and A are basic to the appearance of color in other parts of the plant as well as in the apiculus. Purple color of inner

glumes (lemma and palea), leaves, and nodes was shown to result from the complementary action of C and A with Pr, Pl, and Pn, respectively.

The expected segregation ratio in the F_2 of a cross between a line with purple apiculus and inner glumes and a completely colorless line is given below to illustrate the many color patterns that appear as the result of recombinations of color genes.

<i>Ratio of gene combinations</i>	<i>Color patterns</i>
27 C A Pr -----	Purple apiculus and glumes.
9 C A pr -----	Purple apiculus, colorless glumes.
9 C a Pr -----	Brown (tawny) apiculus and glumes.
3 C a pr -----	Brown (tawny) apiculus, colorless glumes.
16 c -----	All combinations with c are color- less.

Many of the segregation ratios previously reported in publications in Japan and other countries can now be reinterpreted with fewer assumptions in accordance with the above analysis. Other workers had recognized two basic complementary color genes, but the pleiotropic action and the existence of multiple alleles had not been fully realized.

Indian workers (50) have established an allelic series for another set of glume colors: H^m , mottled; H^1 , piebald; H^s , green changing to straw at maturity; and H^t , dark furrow color. These colors appear only in the presence of the gene for strawhull color, Gh ; and with gh , only goldhull colors appear.

Purple bran appears in varieties apparently lacking pigmentation in all other parts and segregates in 3:1 ratios in crosses with colorless bran. A cross between a purple bran line that carried a gene for red bran and a colorless line gave 9 purple-red:3 purple:3 red:1 colorless (9). The red underlaid the purple in such a way that it was possible to separate the first two classes. A cross between a purple bran line having colorless vegetative parts and a line having ordinary bran and partly purple leaves segregated in the F_2 generation in a ratio of 13 colorless or partly purple leaves to 3 fully purple leaves. The results show that an inhibitor gene restricts expression of full purple leaf color. Purple leaf appeared only in the presence of purple bran.

Red rice varieties are grown in southern India, in Ceylon, and in other areas; but red-rice mixtures in white milled rice detract from the appearance. Work reported from Japan (41) showed that red bran color required two genes for expression. A gene Rc for brown bran is basic, and with Rd the bran is bright red. Rd and A are closely linked; this makes it appear that the apiculus color gene is basic for red. In a cross between a red line of the genetic constitution C A Rd Rc and colorless C a rd rc , the segregation is 9 red bran, colored apiculus:3 colorless bran, colored apiculus:3 brown bran, colorless

apiculus:1 both bran and apiculus colorless. In this cross, red bran is found only with colored apiculus and brown bran only with colorless. In the cross C A Rd Rc \times c a rd Rc , on the other hand, red bran occurs with and without colored apiculus; but brown bran never occurs with colored apiculus. The F_2 ratio is 9 red bran, colored apiculus:3 brown bran, colorless apiculus:3 red bran, colorless apiculus:1 both bran and apiculus colorless.

The existence of varieties with life cycles that range from as short a period as 3 months to about 10 months contributes greatly to the wide adaptability of rice to different areas and conditions. Varieties are classified for time of flowering as photosensitive or as insensitive. The photosensitive class includes late-maturing varieties, which remain in a vegetative stage while the days are long but probably enter the flowering stage when the night period reaches a critical length. In Ceylon, differences in varietal response to variations of less than an hour in day length were found and were controlled by one dominant gene for sensitivity (11). Early varieties tend to enter the flowering stage after the completion of a fairly constant vegetative stage.

In Japan, a series of six maturity genes dominant for lateness and having accumulative effects have been postulated (40). The action of these genes is conditioned by temperature. Sampath and Seshu (57) reported an Indian study that dealt with crosses of two varieties from Japan with photosensitive Indian varieties. One Japanese variety was insensitive and the other photosensitive in Japan; but under the temperature and day length conditions at Cuttack, India, both flowered early (48 and 68 days from seeding, respectively). The F_1 plants of crosses of the Indian varieties with the insensitive Japanese variety flowered early, and segregation in the F_2 generation was 3 early:1 late or 15 early:1 late. However, in crosses between the photosensitive Japanese variety and Indian varieties the F_1 plants flowered late and segregation in the F_2 generation was 1 early:3 late or 1 early:15 late. It was assumed that in the crosses with the photosensitive parent, genes involved in temperature responses and modifying the photoperiodic response were segregating. These authors cite a Japanese study in which a gene for late flowering was found to be epistatic to one for early flowering.

In Louisiana, a cross between varieties that headed in 90 and 125 days was studied (8). The F_2 segregation was bimodal and indicated the action of one major gene for earliness.

Disease resistance can be analyzed genetically if distinctly resistant and susceptible classes occur. Specialized races of fungus diseases must be taken into account; usually segregation is best

determined following inoculation with cultured spores of individual races. Single and duplicate genes for resistance to four races of *Cercospora oryzae* I. Miyake, the fungus that causes narrow brown leaf spot, have been determined (27). No linkage was found between genes for *Cercospora* resistance and the chromosome marker genes C apiculus color, H^f furrow color, gh goldhull, and wx waxy (26).

Several types of genetic segregation have been reported for inheritance of resistance to *Piricularia oryzae* Cav., the fungus that causes blast. As early as 1922, resistance was reported to be controlled by a single dominant gene (40). However, no work has been reported on segregation of resistance to established races. In 1960, a laboratory study of three crosses was reported from India (7). Survival was controlled by one or two dominant genes, but the surviving plants and the parents showed rather high degrees of susceptibility.

Awns are a conspicuous morphologic character. Although little is known of their physiologic value to the plant, they are supposed to be associated with general hardiness (50) and to offer some protection against pests. Awns are objectionable in threshing and handling the grain. The development of awns varies considerably with environmental conditions. Varieties that show mere tip awns at moderate levels of fertility may develop much more prominent awns at higher levels. In Louisiana, the Caloro variety develops awns when seeded very early but may be practically awnless when seeded late. In the F₂ generation, ratios of awned to awnless plants of 3:1, 15:1, and 9:7 have been reported from India, Japan, and the United States. These ratios show, respectively, that single, duplicate, and complementary genes act to produce awns. A study in California (28) showed that fully awned plants differed from awnless by two genes, fully awned from partly awned by one gene, and partly awned from awnless by one gene.

Most rice varieties have pubescent leaves and hulls, although a few are essentially glabrous. Pubescence has been eliminated from the varieties grown in the Southern United States. In most varieties, a single gene pair Gl:gl controls the development of plant hairs on all outer surfaces of the plant. However, some varieties have some pubescence on the leaf surface, although the lemma and palea are smooth. Nagao, Takahashi, and Kinoshita (43) reported the segregation in crosses of the latter type with ordinary pubescent Japanese types. Three classes of pubescence plus glabrous appeared in the F₂ generation in ratios of 9:3:3:1 and 27:9:21:3. It was concluded that two genes Hl_a and Hl_b together but not singly bring about the development of hairs on the leaf surfaces even in the presence of gl.

The strength of attachment of spikelets to their pedicles is of practical importance to the grower. Shattering (shedding) of grain in the wind, which occurs in red rice, would make it impossible to harvest the crop; whereas at the other extreme, which occurs in some of the Japanese varieties, the attachment is so tight that in combining much grain would remain on the straw. Types that thresh free of the straw yet do not shatter easily are needed for mechanized harvest. Easy threshing Sh is dominant to intermediate or tough threshing sh; but, on the other hand, tough threshing is dominant to intermediate threshing.

Multiple gene inheritance of grain length was reported in a study in the United States (29). In crosses of short × medium, short × long, and medium × long types, variation in length in the F₂ generation was continuous. Similar results, also showing transgressive segregation, were obtained for breadth of grain.

Tillering ability is of great importance where rice is transplanted, but much less so where direct seeding at relatively high rates is practiced. Ramiah and Rao (50) reported from India that the F₁ plants of three crosses were intermediate for number of tillers per plant, and the F₂ progenies showed transgressive segregation. In one cross high correlation between the number of tillers in F₂ plants and their respective F₃ progenies indicated that the controlling genes are limited in number—probably no more than three or four. In another cross the occurrence of numerous F₃ progenies, each comparatively uniform in number of tillers, led to the same conclusion.

Standing ability or lodging resistance is a complex character that is difficult to measure in inheritance studies. In a study reported from India (50), the F₂ progenies of a cross segregated 3 lodging:1 nonlodging, but the latter were low tillering and late maturing.

In Louisiana, a cross between an early-maturing, medium-grain selection and the late-maturing variety Rexoro indicated transgressive segregation for yield (8). F₄ lines were recovered that had yields significantly higher than those of the high-yielding parent, but none had yields significantly lower than those of the low-yielding parent. Higher yield was strongly associated with earlier maturity. No correlation was found between yield and spikelet length and breadth, or between yield and grain weight.

In correlation studies from other countries Ramiah and Rao (50) indicate association of higher yield with number of tillers, number of grains per ear, and plant height.

Genetic information on the quality character of rice is very limited, although the single gene segregation between common and waxy types was one of the first characters studied. The inherit-

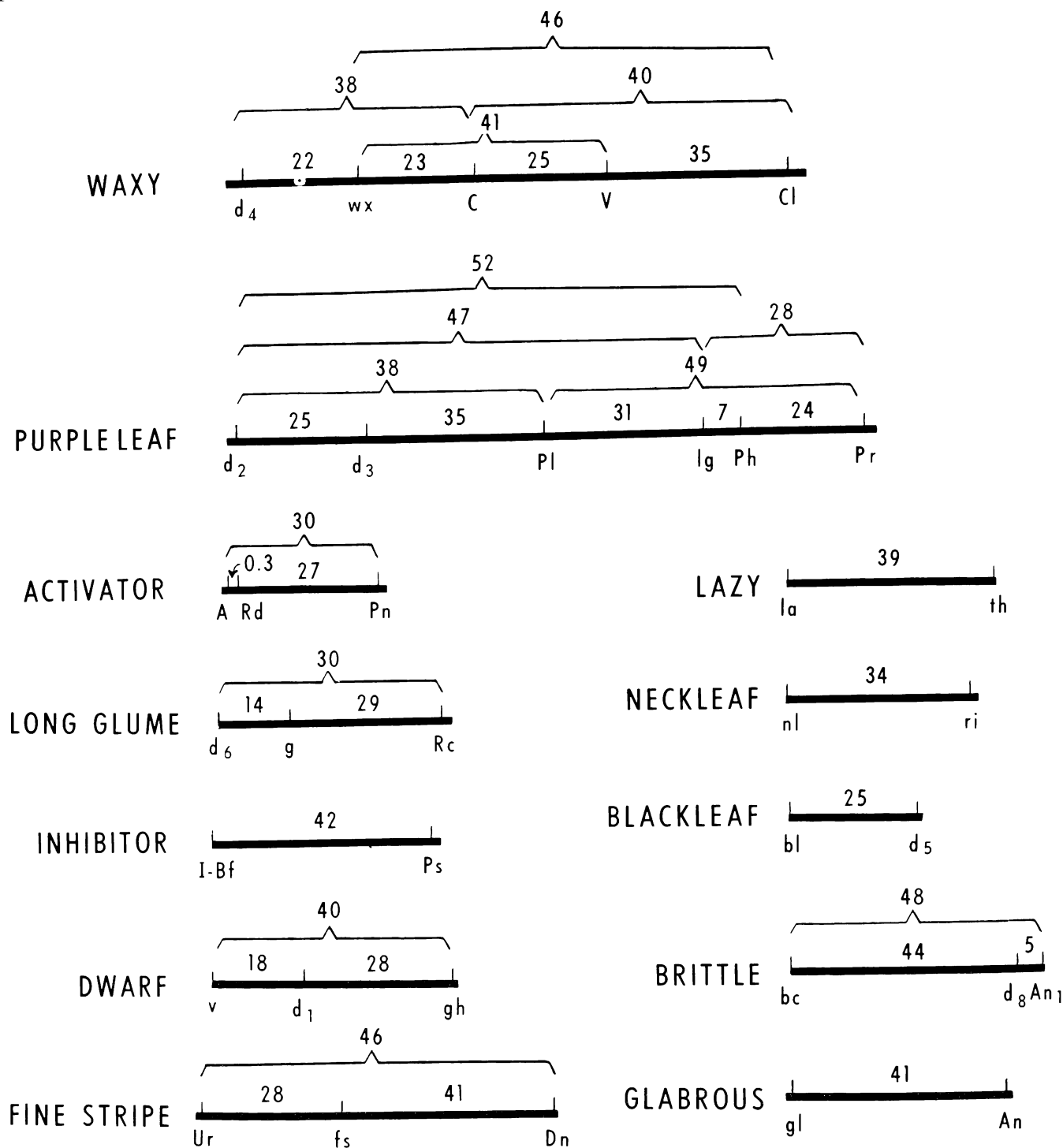


FIGURE 5.—Rice linkage groups.

ance of amylose content as indicated by the iodine value was studied in a cross of Toro (high iodine value) \times Texas Patna (low iodine value) (58). The value in the F_1 generation was low, indicating partial dominance. A bimodal distribution was obtained in the F_2 , indicating dominance of one major gene for low iodine value. An association was shown between low iodine value and colored apiculus; the latter is also a character of the low iodine parent. Recovered lines with high

iodine value were much more numerous in the early-maturing than in the late-maturing group.

Linkage refers to the closeness of association in inheritance of genes located on the same chromosomes. Genes controlling characters that segregate into clear-cut classes and that are viable are useful for determining linkage relationships. Several of the genes for color are suitable marker genes. Easily classified morphologic characters dependent on single genes are also useful, includ-

ing some of the more conspicuous characters such as awns, long outer glumes (of which recessive and semidominant types are known), pubescence, neckleaf, liguleless, lazy (ageotropic), brittle culm, numerous dwarfs, waxy endosperm, and viable types of chlorophyll deficiencies.

In a report from Japan, Nagao and Takahashi (42) presented data that established 12 linkage groups, representing, as expected, the number of chromosomes found in rice. Takahashi (63) has since amplified the information on the linkage groups. The linkage diagrams (maps) shown in

figure 5 are based on the Japanese results. Data from other studies and reviews (2, 23, 24, 25, 38, 63) are provisionally included with the groups to which they appear to belong. Linkages between genes that have been reported but not definitely located on the respective chromosomes are listed in table 5. Linkages between genes that have been reported but have not been assigned to a linkage group are also shown in table 5. Linkage maps of rice are much less complete than those of barley and maize.

TABLE 5.—Linkages not definitely located on the respective chromosomes

Linkages tentatively assigned to groups	Percentage recombination ¹	Authority	Linkages tentatively assigned to groups	Percentage recombination ¹	Authority
WAXY GROUP			LONG GLUME GROUP—		
WX vs. Pla-----	45	Nagao and Takahashi (42).	Con.		
C vs. H ^e -----	29	Ramiah and Rao (50).	Rk vs. I-An-----	31?	Jodon (unpublished).
C vs. Se-----	16	Chandraratna (10).	Pin vs. Rc-----	Unknown	Ramiah and Rao (50).
C vs. Lf-----	32	Yamaguchi (68).	Rc vs. Lf _x ?-----	22	Yamaguchi (69).
C vs. dp-----	Unknown	Nagamatsu and Ohmura. ¹	INHIBITOR GROUP		
C vs. n-----	do	Do. ¹	Ps vs. Psh-----	10	Chao (12).
l vs. d ₂₁ -----	² 17?	Jodon (unpublished).	Ps vs. Apic-----	9	Shafi and Aziz (59).
WX vs. X ₁ -----	Unknown	Oka (1953). ¹	Apic vs. Psh-----	12	Do.
WX vs. Y ₁ -----	do	Do. ¹	Ps vs. Pr-----	2	D'Cruz (17).
PURPLE LEAF GROUP			DWARF GROUP		
Pl vs. An-----	29?	Jodon (unpublished).	gh vs. An ₃ -----	43	Nagao and Takahashi (42).
Pl vs. lop-----	Unknown	Nagamatsu and Ohmura, 1961. ¹	gh vs. P or Pr-----	30	Jodon and Chilton (26).
lg vs. Wh-----	8	Jodon (24, 25).	FINE STRIPE GROUP		
lg vs. Xa-----	Unknown	Nishimura. ¹	None-----		
Pr vs. P-----	32?	Jodon (unpublished).	LAZY GROUP		
P vs. (blackspot)-----	33?	Do.	La vs. d-----	Unknown	Nagamatsu and Ohmura. ¹
Pr vs. lg-----	30	Richharia and others (51).	NECKLEAF GROUP		
Pr vs. Px-----	9	Do.	nl vs. An-----	32?	Jodon (unpublished).
Px vs. Psh-----	6	Do.	GLABROUS GROUP		
Pr vs. gh-----	32	Jodon (24, 25).	gl vs. H ^e -----	39	Nagao and Takahashi (42).
Pr vs. h-----	36	Do.	LINKAGES NOT ASSIGNED TO LINKAGE GROUP		
gh vs. Wh-----	Unknown	Do.	Rk vs. An-----	14 and 24	Anandan (6).
Ps vs. Pr-----	do	Hsieh (20).	Bh vs. An-----	21	Kuang (36).
d vs. Pl-----	do	Do.	Bh vs. Pin?-----	17	Parnell, Ranga-swami Ayyangar, and Ramiah (47).
Pi vs. lg-----	do	Do.	An vs. d-----	11	Kuang (36).
ACTIVATOR GROUP			Pr? vs. Plg?-----	13	Hebert (18).
A vs. bn-----	23	Hsieh (19).	Pr? vs. Pin-----	10	Do.
bn vs. d ₂₂ -----	28	Do.	Purple collar vs. Prp	13	Breaux (9).
d ₂₂ vs. lgt-----	16	Do.	Psh vs. Prp-----	16	Comeaux (16).
lgt vs. bn-----	30	Do.	bl vs. Prp-----	Unknown	Jodon (unpublished).
A vs. d ₂₂ -----	37	Do.	d ₂₁ vs. Prp-----	do	Do.
Rd vs. Pin-----	21	Ramiah and Rao (50).	sk vs. Prp-----	do	Ramiah and Rao (50).
LONG GLUME GROUP					
d ₆ vs. d ₇ -----	39	Nagao and Takahashi (42).			
g vs. Rk-----	8	Kadam and D'Cruz (31).			
Apic vs. g-----	17	Do.			

¹ As reported by Takahashi (63).

² Entries followed by question marks have not been verified and may be changed as more information becomes available.

Selected References

- (1) ANONYMOUS.
1950. WORLD CATALOGUE OF GENETIC STOCKS—RICE. Food and Agr. Organ. United Nations, 30 pp. [Mimeographed.]
- (2) ———
1963. RICE GENE SYMBOLIZATION AND LINKAGE GROUPS. U.S. Agr. Res. Serv. ARS 34-28. 56 pp.
- (3) ADAIR, C. R.
1934. STUDIES ON BLOOMING IN RICE. *Agron. Jour.* 26: 965-973.
- (4) ———
1936. STUDIES ON GROWTH IN RICE. *Agron. Jour.* 28: 506-514.
- (5) AKIMOTO, S., and TOGARI, Y.
1939. VARIETAL DIFFERENCES IN PANICLE DEVELOPMENT OF RICE WITH REFERENCE TO EARLY OR LATE TRANSPLANTING. *Crop Sci. Soc. Japan, Proc.* 11(1): 7-14.
- (6) ANANDAN, M.
1928-33. RPTS. ON AGR. STAS., MADRAS DEPT. AGR., ADUTURIA, 1927-28 AND 1932-33. [Original not seen. Reported by Ramiah and Rao (50).]
- (7) BHAPKAR, D. G., and D'Cruz, R.
1960. INHERITANCE OF BLAST RESISTANCE IN RICE. *Poona Agr. Col. Mag.* 51(2): 23-25.
- (8) BOLICH, C. N.
1957. INHERITANCE OF SEVERAL ECONOMIC QUANTITATIVE CHARACTERS IN RICE. Unpublished thesis, Ph.D., La. State Univ.
- (9) BREAUX, NORRIS.
1940. CHARACTER INHERITANCE, FACTOR INTERACTION, AND LINKAGE RELATIONS IN THE F_2 OF A RICE CROSS. Unpublished thesis, Ph.D., Dept. of Agron., La. State Univ., 38 pp.
- (10) CHANDRARATNA, M. F.
1953. A GENE FOR PHOTOPERIOD SENSITIVITY IN RICE LINKED WITH APICULUS COLOUR. *Nature* 171: 1162-1163.
- (11) ———
1955. GENETICS OF PHOTOPERIODIC SENSITIVITY IN RICE. *Jour. Genet.* 53: 215-223.
- (12) CHAO, L. F.
1928. LINKAGE STUDIES IN RICE. *Genetics* 13: 133-169.
- (13) CHATTERJEE, D.
1948. A MODIFIED KEY AND ENUMERATION OF THE SPECIES OF *ORYZA* LINN. *Indian Jour. Agr. Sci.* 18(3): 185-192.
- (14) ———
1951. NOTE ON THE ORIGIN AND DISTRIBUTION OF WILD AND CULTIVATED RICES. *Indian Jour. Genet. and Plant Breeding* 11(1): 18-22.
- (15) CHEVALIER, A.
1932. NOUVELLE CONTRIBUTION A L'ETUDE SYSTEMATIQUE DES *ORYZA*. *Rev. de Bot. Appl. et d'Agr. Trop.* 12: 1014-1032.
- (16) COMEAUX, D. J.
1946. AN INHERITANCE AND LINKAGE STUDY OF VIRESCENCE AND OTHER FACTORS IN RICE, *ORYZA SATIVA*. Unpublished thesis, La. State Univ., 50 pp.
- (17) D'Cruz, R.
1960. A LINKAGE BETWEEN TWO BASIC GENES FOR ANTHOCYANIN COLOUR IN RICE. *Sci. and Cult. [India]* 25: 534-536.
- (18) HEBERT, L. P.
1938. A GENETIC STUDY OF COLOR AND CERTAIN OTHER CHARACTERS IN RICE. Unpublished thesis, La. State Univ., 57 pp.
- (19) HSIEH, S. C.
1960. GENIC ANALYSIS IN RICE. I. COLORATION GENES AND OTHER CHARACTERS IN RICE. *Acad. Sinica Bot. Bul.* 1: 117-132.
- (20) ———
1961. ANALYSIS OF GENES FOR BLAST DISEASE RESISTANCE CAUSED BY *PIRICULARIA ORYZAE*. Symp., Studies on Cause of Low Yield of Rice in Tropical and Sub-Tropical Regions, Proc. Spec. Pub. Taiwan Agr. Res. Inst. 3: 45-52.
- (21) HUTCHINSON, J. B., RAMIAH, K., and MEMBERS OF TWO SPECIAL SUBCOMMITTEES.
1938. THE DESCRIPTION OF CROP-PLANT CHARACTERS AND THEIR RANGES OF VARIATION. INTRODUCTION. *Indian Jour. Agri. Sci.* 8(5): 567-569; II. VARIABILITY IN RICE. 8(5): 592-616.
- (22) ITO, H., and AKIHAMA, T.
1962. AN APPROACH FOR THE SYMBOLIZATION OF COLORS IN RICE PLANTS AND ITS ADOPTION FOR THE CLASSIFICATION OF RICE VARIETIES. *Jap. Jour. Breeding* 12: 221-225. [In Japanese. English summary.]
- (23) JODON, N. E.
1948. SUMMARY OF RICE LINKAGE DATA. U.S. Dept. Agr., Bur. Plant Indus., Soils, and Agr. Engin., 34 pp. [Mimeographed.]
- (24) ———
1955. PRESENT STATUS OF RICE GENETICS. *Agr. Assoc. China, Jour.* (n.s.) 10: 5-21.
- (25) ———
1956. PRESENT STATUS OF RICE GENETICS. *Agr. Assoc. China, Jour.* (n.s.) 14: 69-73.
- (26) ——— and CHILTON, S. J. P.
1946. SOME CHARACTERS INHERITED INDEPENDENTLY OF REACTION TO PHYSIOLOGIC RACES OF *CERCOSPORA ORYZAE* IN RICE. *Amer. Soc. Agron. Jour.* 38: 864-872.
- (27) ———, RYKER, T. C., and CHILTON, S. J. P.
1944. INHERITANCE OF REACTION TO PHYSIOLOGIC RACES OF *CERCOSPORA ORYZAE* IN RICE. *Amer. Soc. Agron. Jour.* 36: 497-507.
- (28) JONES, J. W.
1933. INHERITANCE OF CHARACTERS IN RICE. *Jour. Agr. Res.* 47: 771-782.
- (29) ———, ADAIR, C. R., BEACHELL, H. M., and DAVIS, L. L.
1935. INHERITANCE OF EARLINESS OF LENGTH OF KERNEL IN RICE. *Amer. Soc. Agron. Jour.* 27: 910-921.
- (30) JULIANO, J. B., and ALDAMA, M. J.
1937. MORPHOLOGY OF *ORYZA SATIVA* LINNAEUS. *Philippine Agr.* 26: 1-134.
- (31) KADAM, B. S., and D'Cruz, R.
1960. GENIC ANALYSIS IN RICE. III. INHERITANCE OF SOME CHARACTERS IN TWO CLUSTERED VARIETIES OF RICE. *Indian Jour. Genet. and Plant Breeding* 20: 79-84.
- (32) KATAYAMA, TUKUDA.
1931. ANALYTICAL STUDIES OF TILLERING IN PADDY RICE. *Jour. Imp. Agr. Exp. Sta.* 1(4): 327-374. [English summary, 371-374.]
- (33) KATO, S., KOSAKA, H., and HARA, S.
1928. ON THE AFFINITY OF RICE VARIETIES AS SHOWN BY THE FERTILITY OF HYBRID PLANTS. *Kjusu Imp. Univ., Fakult. Terkult. Bul. Sci. Rpt.* 3: 132. [In Japanese.]
- (34) ———, KOSAKA, H., and HARA, S., and others.
1930. ON THE AFFINITY OF THE CULTIVATED VARIETIES OF RICE PLANTS, *ORYZA SATIVA* L. *Kyushu Imp. Univ., Dept. Agr. Jour.* 2(9): 241-276.

- (35) KIHARA, H.
1959. CONSIDERATIONS ON THE ORIGIN OF CULTIVATED RICE. *Seiken Zihō*, 10: 68-83.
- (36) KUANG, H. H.
1951. STUDIES ON RICE CYTOLOGY AND GENETICS AS WELL AS BREEDING WORK IN CHINA. *Agron. Jour.* 43: 387-397.
- (37) MATSUDA, K.
1929. ON THE DEVELOPMENT OF RICE KERNELS. *Nōgaku Kwaihō* (Sci. Agr. Soc. [Japan] Jour.), No. 314, 34 pp.
- (38) MATSUURA, H.
1933. *ORYZA SATIVA. His A Bibliographical Monograph on Plant Genetics (Genic Analysis)*, 1900-1929. Ed. 2, pp. 240-265. Hokkaido Imp. Univ., Sapporo.
- (39) MIZUSHIMA, U.
1948. STUDY ON SEXUAL AFFINITY AMONG RICE VARIETIES, *ORYZA SATIVA* L. I. ANALYSIS OF AFFINITY OF JAPANESE, AMERICAN, AND JAVANESE VARIETIES. *Seibutu* 3(2): 41-52.
- (40) NAGAI, I.
1959. *JAPONICA RICE. ITS BREEDING AND CULTURE*. 843 pp. Yokendo, Ltd., Tokyo.
- (41) NAGAO, S.
1951. GENIC ANALYSIS AND LINKAGE RELATIONSHIP OF CHARACTERS IN RICE. In Demerec, M., ed., *Adv. in Genet.* 4: 181-212.
- (42) ——— and TAKAHASHI, M.
1963. TRIAL CONSTRUCTION OF TWELVE LINKAGE GROUPS IN JAPANESE RICE. *Hokkaido Imp. Univ., Faculty Agr. Jour.* 53: 72-130.
- (43) ——— TAKAHASHI, M., and KINOSHITA, T.
1960. GENETICAL STUDIES ON RICE PLANT. XXV. INHERITANCE OF THREE MORPHOLOGICAL CHARACTERS. PUBESCENCE OF LEAVES AND FLORAL GLUMES, AND DEFORMATION OF EMPTY GLUMES. *Hokkaido Imp. Univ., Faculty Agr. Jour.* 51: 299-314. [In English.]
- (44) NANDI, H. K.
1936. THE CHROMOSOME MORPHOLOGY, SECONDARY ASSOCIATION AND ORIGIN OF CULTIVATED RICE. *Jour. Genet.* 33(2): 315-336.
- (45) OKA, H. I.
1958. INTERVARIETAL VARIATION AND CLASSIFICATION OF CULTIVATED RICE. *Indian Jour. Genet. and Plant Breeding* 18(2): 79-89.
- (46) ——— and CHANG, W. T.
1962. RICE VARIETIES INTERMEDIATE BETWEEN WILD AND CULTIVATED FORMS AND THE ORIGIN OF THE JAPONICA TYPE. *Acad. Sinica Bot. Bul.*, 3(1): 109-131.
- (47) PARNELL, F. R., RANGASWAMI AYYANGAR, G. N., and RAMIAH, K.
1917. THE INHERITANCE OF CHARACTERS IN RICE. I. *India Dept. Agr. Mem., Bot. Ser.* 9: 75-105.
- (48) RAMIAH, K., and GHOSE, R. L. M.
1951. ORIGIN AND DISTRIBUTION OF CULTIVATED PLANTS OF SOUTH ASIA—RICE. *Indian Jour. Genet. and Plant Breeding* 11(1): 7-13.
- (49) ——— and NARASIMHAN, M.
1936. DEVELOPMENTAL STUDIES IN RICE. I. *Madras Agr. Jour.* 24(2): 50-66.
- (50) ——— and RAO, M. B. V. N.
1953. RICE BREEDING AND GENETICS. *Indian Council Agr. Res. Sci. Monog.* 19, 360 pp.
- (51) RICHHARIA, R. H., MISRO, B., BUTANY, W. T., and SEETHARAMAN, R.
1960. LINKAGE STUDIES IN RICE (*ORYZA SATIVA* L.). *Euphytica* 9: 122-126.
- (52) RODRIGO, P. A.
1925. POLLINATION AND THE FLOWER OF RICE. *Philippine Agr.* 14(3): 155-171.
- (53) ROSCHEVICZ, R. J.
1931. A CONTRIBUTION TO THE KNOWLEDGE OF RICE. *Bul. Appl. Bot., Genet., and Plant Breeding* 27(4): 1-133. [English summary, pp. 119-133.]
- (54) SAKAI, K. I.
1935. CHROMOSOME STUDIES IN *ORYZA SATIVA* L. I. THE SECONDARY ASSOCIATION OF THE MEIOTIC CHROMOSOMES. *Jap. Jour. Genet.* 11(3): 145-156. [English summary, p. 154.]
- (55) SAMPATH, S., and GOVINDASWAMI, S.
1958. WILD RICES OF ORISSA—THEIR RELATIONSHIP TO CULTIVATED VARIETIES. *Rice News Teller*, July.
- (56) ——— and RAO, M. B. V. N.
1951. INTERRELATIONSHIPS BETWEEN SPECIES IN THE GENUS *ORYZA*. *Indian Jour. Genet. and Plant Breeding* 11: 14-17.
- (57) ——— and SESHU, D. V.
1961. GENETICS OF PHOTOPERIOD RESPONSE IN RICE. *Indian Jour. Genet. and Plant Breeding* 21: 38-42.
- (58) SEETHARAMAN, RAMASWAMY.
1959. THE INHERITANCE OF IODINE VALUE IN RICE AND ITS ASSOCIATION WITH OTHER CHARACTERS. Ph.D. Diss., La. State Univ., 65 pp.
- (59) SHAFI, M., and AZIZ, M. A.
1959. THE INHERITANCE OF ANTHOCYANIN PIGMENT IN THE OUTERGLUME AND APICULUS OF RICE. *Agr. Pakistan* 10: 217-232.
- (60) SHASTRY, S. V. S., RAO, D. R. R., and MISRA, R. N.
1960. PACHYTENE ANALYSIS IN *ORYZA*. I. CHROMOSOME MORPHOLOGY IN *ORYZA SATIVA*. *Indian Jour. Genet. and Plant Breeding* 20(1): 15-21.
- (61) SMITH, W. D., DEFFES, J. J., BENNETT, C. H., and others.
1938. EFFECT OF DATE OF HARVEST ON YIELD AND MILLING QUALITY OF RICE. *U.S. Dept. Agr. Cir.* 484, 20 pp.
- (62) TAKAHASHI, M.
1957. ANALYSIS ON APICULUS COLOR GENES ESSENTIAL TO ANTHOCYANIN COLORATION IN RICE. *Hokkaido Imp. Univ., Faculty Agr. Jour.* 50: 266-362, 6 plates. [In English.]
- (63) ———
1964. LINKAGE GROUPS AND GENE SCHEMES OF SOME STRIKING MORPHOLOGICAL CHARACTERS IN JAPANESE RICE. In *Rice Genetics and Cytogenetics*, Symp. Proc., Internatl. Rice Res. Inst., Los Banos, Philippines. pp. 215-236. Elsevier Pub. Co., Amsterdam, London, and New York.
- (64) TATEOKA, T.
1963. TAXONOMIC STUDIES OF *ORYZA*. III. KEY TO THE SPECIES AND THEIR ENUMERATION. *Bot. Mag. Tokyo* 76: 165-173.
- (65) TERADA, S.
1928. EMBRYOLOGICAL STUDIES IN *ORYZA SATIVA* L. *Hokkaido Imp. Univ., Col. Agr. Jour.* 19(4): 245-260. [In English.]
- (66) TERAOKA, H., and MIDUSIMA, U.
1939. SOME CONSIDERATIONS ON THE CLASSIFICATION OF *ORYZA SATIVA* L. INTO TWO SUBSPECIES SO-CALLED 'JAPONICA' AND 'INDICA.' *Jap. Jour. Bot.* 10(3): 213-258.

- (67) TING, YING.
1949. ORIGINATION OF THE RICE CULTIVATION IN CHINA. Rice Expt. Sta., Sun Yatsen Univ., Canton, China. Col. of Agr., Agron. Bul. 7, Pub. series III, 18 pp. [Resumé in English.]
- (68) YAMAGUCHI, Y.
1921. ETUDES D'HERÉDITÉ SUR LA COULEUR DES GLUMES CHEZ LE RIZ. Bot. Mag. [Tokyo] 35: 106-112. [English review in Internatl. Rev. Sci. and Pract. Agr. [Rome] 12: 1399-1401.]
- (69) ————
1929. FURTHER CONTRIBUTIONS TO THE KNOWLEDGE OF THE SECOND (S.M.) LINKAGE GROUP IN RICE. Nôgaku Kenkyu [Studies in Agr. Sci.] Japan 13: 135-172. [In Japanese.]
- (70) YEH, B., and HENDERSON, M. T.
1961. CYTOGENETIC RELATIONSHIPS BETWEEN CULTIVATED RICE, *ORYZA SATIVA* L., AND FIVE WILD SPECIES OF *ORYZA*. Crop Sci. 1: 445-450.
- (71) YUNG, C. T.
1938. DEVELOPMENTAL ANATOMY OF THE SEEDLING OF THE RICE PLANT. Bot. Gaz. 99(4): 786-802.

RICE BREEDING AND TESTING METHODS IN THE UNITED STATES

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History and Objectives

Rice improvement in the United States has been discussed by Jones (55),¹ and the descriptions and performance of varieties developed have been reported by several authors (1, 2, 25, 42, 43, 48, 52, 57, 58, 59, 67). Although some work to improve United States rice varieties was done before 1909, it was not until about then that comprehensive, cooperative rice-breeding studies were started in the United States. Objectives of the rice-breeding program and methods used have been described (7, 18, 55, 69). According to a report by the Rice Millers Association,² all rice varieties grown in the United States in 1963 evolved from these cooperative rice-breeding experiments.

Although introductions were made by individuals after the original introductions into South Carolina in the 17th century, little effort was made by Federal or State agencies to improve rice varieties until work was started by the U.S. Department of Agriculture in 1899. At that time Seaman A. Knapp, an explorer in the Division of Botany, introduced from Japan 10 tons of Kiusshu rice that was distributed in southwestern Louisiana and probably in eastern Texas, where he arranged farm demonstrations of rice varieties and cultural methods. Many varieties were introduced and tested by Department workers on demonstration farms in Louisiana and Texas, and later in Arkansas and California, before the establishment of rice experiment stations in these States.

The Rice Experimental Station at Crowley, La., was established in 1909. The Biggs Rice Field Station at Biggs, Calif., (now the Rice Experiment Station) and the Rice Experiment Station at Beaumont, Tex., (now the Rice-Pasture Research and Extension Center) were established in 1912. The Rice Branch Experiment Station at Stuttgart, Ark., was established in 1926. Rice investigations were started at the Delta Branch Experiment Station, Stoneville, Miss., about 1951. Rice-breeding investigations are conducted cooperatively by the U.S. Department of Agriculture and the State agricultural

experiment station at each of these locations. The rice-breeding studies were started in Louisiana in 1909, in California in 1912, and in Arkansas in 1931. Although a comprehensive rice-breeding program was not started in Texas until 1931 and in Mississippi until 1958, some breeding work had been done in these States before these dates.

Most of the early work consisted of testing selections from foreign introductions and commercial fields. Many varieties, such as Caloro, Colusa, Fortuna, Nira, and Rexoro, were developed and released from 1909 to about 1937.

S. L. Wright, a farmer in Louisiana, developed several rice varieties by selection. These varieties probably were progenies of natural hybrids between varieties, such as the long-grain Honduras and the short-grain Shinriki. The most widely grown varieties developed by Wright were Blue Rose and Early Prolific, which are medium-grain types, and Edith and Lady Wright, which are long-grain types. None of these varieties were grown in 1963, but they were the leading varieties in the southern rice area from about 1915 to 1940.

During the early years, no attempt was made to improve varieties by hybridization. Although a few hybrids had been made at experiment stations in the southern rice area at an earlier date, it was not until after 1922 that this method of breeding was used.

The primary objective in rice breeding in the United States is to develop varieties that will assure a maximum and stable production of the types of rice required by producers and consumers. Emphasis is given to developing short-season varieties. Short-, medium-, and long-grain types—with a wide maturity range within each grain type class—should be developed. The objectives of that program are to develop varieties that (1) germinate quickly and grow rapidly in the seedling stage; (2) tolerate low temperature in the germinating, seedling, and flowering stages and tolerate low irrigation water temperatures during the entire growing season; (3) are resistant to alkaline and saline soils and to salt in the irrigation water; (4) are resistant to diseases and insects; (5) have short, stiff straw and resist lodging; (6) respond to and make efficient use of maximum rates of fertilizer; (7) mature uni-

¹ Italic numbers in parentheses refer to Selected References, p. 62.

² Shown printed in Rice Jour. 66(12): 14-15. 1963.

formly and produce seed that has a period of dormancy so that the grain will not germinate when harvest is delayed by rain; (8) produce maximum field and milling yields when grown under a wide range of environmental conditions; and (9) have the desired cooking and processing qualities required by domestic and foreign trade.

Each of these objectives is important in each rice-producing area in the United States, although some of the objectives are more important in one area than in another. For example, cold tolerance, especially tolerance to cold irrigation water, is more important in California than in the southern rice area. Disease resistance, on the other hand, is more important in the southern rice area than in California.

Cultural Methods and Equipment for Breeding Rice in the United States

Land for rice-breeding experiments should be of uniform soil type and topography. A gradual and uniform slope is desirable to afford reason-

ably rapid drainage when necessary. However, the slope should be such that blocks of three-tenth acre or larger can be uniformly irrigated without contour levees.

In the United States it is customary to locate roadways at 200- to 300-foot intervals running in the direction of the fall of the land and wide enough to accommodate field equipment and other vehicles. The road ditches are used for drainage and are paralleled by border levees. The entire area should be graded to a uniform slope before roadways and irrigation laterals are constructed. Cross levees at designated points divide the field into areas of approximately one-tenth acre that can be irrigated or drained independently (fig. 6). Larger blocks can be formed by eliminating one or more cross levees. Irrigation laterals parallel roadways and are located midway between the roadways or directly adjacent to one side of the roadways.

Ricefield machinery is used to build levees. In heavy clay soils, a steel-bladed levee builder (fig.



FIGURE 6.—Seeded nursery plots. Some of the plots are irrigated.



FIGURE 7.—Constructing levees in the nursery with a steel-bladed levee builder.

7) is used; in the more loamy soils, a disk-type levee builder (fig. 8) is used. Usually the cross levees have an 8- to 10-foot base. A concrete levee packer is useful in packing newly constructed levees. A concrete tile, 4 to 6 inches in diameter, is placed at the lower end of each block to drain the water into the road ditch so that it will hold the irrigation water. The tile is closed with a metal plate. Sometimes plastic tube siphons are used to irrigate from the lateral or to drain the water into the road ditch.

In the southern rice area, it is customary to plow down the cross levees after each rice crop and to cultivate the fields with ricefield equipment. The irrigation laterals and border levees may or may not be torn down. After cross levees have been plowed down, the areas are disked or plowed and are leveled with a land plane. A 3-year rotation system is practiced in Arkansas and Louisiana. In Arkansas, the land may be cropped to soybeans the first year. The soybeans may be harvested or turned under or disked into the ground as green manure, after which a winter grain crop may be sown. The grain crop may be overplanted with lespedeza the following spring. The grain crop is harvested in early summer, and the lespedeza is harvested for hay or seed in the summer or fall. The field is plowed or disked, and land is leveled during the winter and early spring preparatory to seeding rice the following year. In Louisiana, the land is fallowed when not in rice.

A 3-year rotation system is also practiced in

Texas. It consists of 1 year of rice followed by 2 years of summer fallow. The first summer after rice is grown and harvested, the field is fallowed and then clover or ryegrass is sown in the fall. The crop is harvested for hay or seed in the spring, and the field is summer-fallowed throughout the second summer. Land is leveled during the second summer as time and weather permit.

On clay soils the cross levees are reconstructed in the late fall or winter before the fields are seeded again with rice. After cross levees are constructed, the land is prepared by using lift-type implements attached to a lightweight farm tractor. On silt loam soils the cross levees may be made immediately after seeding.

In California, a 2-year rotation generally is used in rice-breeding nurseries. The land is plowed in the winter or early spring after the rice crop has been grown and harvested. The fields usually are irrigated one or more times during the summer when they are not cropped to rice to germinate weed, grass, and rice seeds. The field is cultivated after each irrigation to destroy the plants that emerge.

Permanent levees are maintained in some of the areas used for rice nurseries. In other areas, plastic levees are used, or earthen levees are constructed with a bulldozer or front-end loading tractor each year before seeding.

Weeds and grass are controlled on lateral and drainage ditch banks, levees, and alleyways in rice by spraying with a contact herbicide.

Various types of seeding equipment are used.



FIGURE 8.—Constructing levees in the nursery with a disk-type levee builder.

In field plot varietal experiments, seeds are sown with small grain drills or specially equipped drills. In yield trials on nursery plots or in experiments where multiple seed sources are involved, belt-type seeders (fig. 9) or other readily cleaned drills are used for seeding. Breeding nurseries involving numerous panicle-row selections are sown by dribbling seed into a single-row manually operated drill (fig. 10) or a multiple-row power-operated drill.

On experimental plots uniform application of known amounts of fertilizer materials is difficult. A basal application of phosphorus and potassium may be applied with a conventional fertilizer distributor before seeding rice or to one of the other crops grown in rotation with rice. Although the fertilizer usually is distributed by a tractor-drawn implement, it may be distributed by airplane. In the southern rice area, the nitrogen fertilizer for breeding trials usually is applied as a topdressing, although sometimes part or all is applied at seeding time.

Various methods and devices have been used to apply fertilizer to rice grown in breeding nurseries. Weighed amounts of fertilizer are applied by hand as a topdressing. Mechanized fertilizer distributors have been tried with only limited success. Most devices are slower than hand application, do not apply or distribute uniform amounts of fertilizer, and can be used only on relatively dry soil.

At Stuttgart, Ark., a manually operated "planter" is used to apply nitrogen fertilizer be-



FIGURE 9.—Belt seeder, mounted on a small tractor, used for seeding nursery yield experiments.



FIGURE 10.—Manually operated seeder used to seed selections.

tween alternate rows when the soil is dry (fig. 11). At Crowley, La., a single-row seeder that has an agitator-type fertilizer attachment with a separate shoe places fertilizer just below the seed.

For a number of years a fertilizer distributor attached to a 3-row seeder was used at Beaumont, Tex. This drill used regular grain drill fertilizer distributor parts. Top-feed and other hopper-type distributors have been used with limited success to topdress plots. A force-feed type distributor that drops the fertilizer on the soil surface is fairly successful (fig. 12). Cross-plot fertilizing with this type distributor appears to be desirable in overcoming irregularities of distribution.

Because rice nurseries are likely to be muddy at harvesttime, mechanical harvesting equipment is not used. Hand sickles are used to harvest small plots; combine harvesters may be used to harvest large plots.

Bundles from small plots are air dried by hanging in a drying shed or by using heated-air driers. When dried by heated air, the bundles are placed in drying trays as harvested and dried over a tunnel or rack-type drying unit with forced heated



FIGURE 11.—A distributor used to apply nitrogen fertilizer between the rows as a topdressing.

air (fig. 13). Bundles are left in the trays until the grain is ready to be threshed.

Bundles from large plots are threshed in a Vogel thresher (fig. 14) or a modified Kansas-type nursery thresher (fig. 15). Sometimes the concave teeth are removed to reduce breakage. Threshing rice is primarily a stripping action, and breakage is avoided when concave teeth are not used and cylinder speed is reduced. Breakage caused by improper adjustment of the thresher should be avoided because it causes a bias of grain yield and milling quality.

In some instances, bundles are placed on the cross levees for a few hours after cutting and are threshed the same day. The threshed grain is placed in cloth bags and artificially dried with forced air heated to between 90° and 100° F.

Threshed samples usually are cleaned before weighing for yield determinations. It may also be necessary to break off awns and attached fragments of rachises. This is accomplished by placing the sample in a section of automobile inner-tube and pounding several times. An easily cleaned aspirator, dockage machine, or small fanning machine can be used to remove foreign material. If the threshed samples are relatively free from foreign material, the grain weight can be obtained before cleaning.



FIGURE 12.—A force-feed fertilizer used to distribute nitrogen as a topdressing.

Maintenance of viable seed of varieties and breeding lines is important in a rice-breeding program. The main causes of rapid deterioration of seed viability are moisture content of the seed and storage temperature. A method of drying the seed and storage facilities with low humidity and low temperatures are needed.

The moisture content of the grain is probably more important than temperature in retaining viability. Rice with a moisture content of 10 percent or below (wet basis) retained viability for several years at Beaumont, Tex. The temperature in the storage room ranged from 70° to 90° F., and the relative humidity was below 50 percent most of the time.

The moisture content of rough rice can be reduced to 4.7 percent (wet basis) when stored 42 days over a saturated solution of lithium chloride (60). The moisture content of rice can be reduced to about 6 percent with a silica gel drying unit (fig. 16). Rice reduced to this moisture content probably will retain viability for 5 years or longer when stored at room temperatures.

At Beaumont, Tex., seed of rice varieties, breeding lines, and genetic stocks is dried in a silica gel drier to about 6-percent moisture and stored with silica gel in sealed 1.2-cubic foot metal containers at about 34° F. About 2 pounds of silica gel is put in each container. An indicator, such as cobalt chloride crystals or paper, that changes



FIGURE 13.—Drying bundles of rice in trays with forced heated air.

color with increase in moisture is used, so that an increase in moisture is easily detected. The silica gel is usually changed every 2 years. Seed can be stored in polyethylene bags with silica gel. However, since these bags do not exclude all the moisture, the silica gel must be changed more frequently.

At Crowley, La., and Beltsville, Md., seed is stored at a temperature of about 0° F. Seed stored in this manner has retained its viability for more than 20 years.

Breeding Methods

The three major breeding methods commonly used for small grain have been used in rice breeding (55). These are (1) introduction of varieties from foreign countries, (2) selection of pure lines from commercial and introduced varieties, and (3) creation of new varieties by hybridization followed by selection. Irradiation breeding also has been used in the United States.

The varieties now grown in the United States were developed by using progressively the three major methods. For example, the Gulfrose variety was selected from the progeny of a cross between a selection from an introduced variety and a pure line selection from a commercial variety.

Introduction

The introduction of varieties from other countries has been and still is an important source of germ plasm for rice breeders in the United States. Some of the introduced varieties have been developed by breeders in the country of origin, and others have been indigenous varieties grown for many years by farmers in the country of origin.



FIGURE 14.—Threshing breeder seed with a Vogel thresher.

According to Jones (55), few varieties were introduced from about 1685 to 1889. It became evident then that the varieties being grown in the United States were not as productive as varieties grown in other countries. Starting about 1890 and continuing to the present, many varieties have been introduced. Jones (55) listed and described nine varieties that were introduced from other countries and grown in the United States. These were Carolina Gold, Carolina White, Early Wataribune, Honduras, Kiushu, Omachi, Onsen, Shinriki, and Wataribune. About 1935, Asahi was introduced from Japan by T. M. Sabora, a Texas rice farmer. He increased this variety for commercial production about 1940 (57). Thus, there have been at least 10 introduced varieties that have been grown rather extensively. None of these varieties are now of commercial importance.

Varieties now introduced into the United States are grown the first year in a greenhouse away from rice production centers to avoid the introduction of diseases and insects. The seed produced in the greenhouse then is sown in a single-row plot at one of the rice experiment stations. Notes are taken on such characters as seedling vigor, straw strength, plant height, length of growing season, grain type, kernel characters, and reaction to diseases and insects. Whether the variety is a pure line or consists of mechanical or hybrid mixtures is also noted. Varieties that appear to have no desirable characters are discarded. Varieties that have some but not all desirable characters are held in reserve for possible future use in the breeding program. Varieties that look promising in all respects in the



FIGURE 15.—Threshing bundles of rice from nursery yield experiment with a modified Kansas nursery thresher.

preliminary trials are tested for at least 3 years in replicated yield trials and are evaluated for disease reaction and cooking quality. When a variety is proved to be superior to commercial varieties, the seed is purified and increased and seed of the new variety is distributed to farmers.

Selection

Selections from introduced or commercial varieties have been an important source of rice varieties in this country. Practically all of the varieties grown in the United States from 1920 to about 1945 were developed by this method.

Jones (55) named the breeders who participated in this work from about 1900 to about 1930. Most of these breeders were employees of the U.S. Department of Agriculture. Chambliss and Jenkins (25) listed and described six varieties that were developed by selection. These are Acadia, Delitus, Evangeline, Salvo, Tokalon, and Vintula. These six varieties were not grown extensively but probably were important for a few years in local areas in Louisiana. Ten other varieties developed by selection and listed and briefly described by Jones (55) are Blue Rose, Caloro, Colusa, Early Prolific, Edith, Fortuna, Lady Wright, Nira, Rexoro, and Shoemed. Other varieties developed by pure line selection are Conway (29), Sunbonnet (42), Bluebonnet 50 (57), and Iola, Latex, Mortgage Lifter, Storm Proof, and Zenith (58). Other selections have been made by farmers and grown locally for a few years.

Selection is a relatively easy method for breeding rice, but it takes many years to develop a variety by this method. The procedure is to select a large number of plants or panicles from a variety that consists of diverse types. These selections are sown in single-row plots and care-

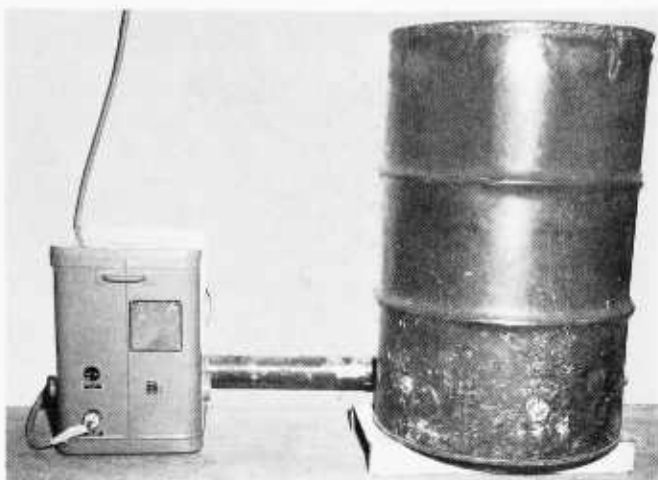


FIGURE 16.—Silica gel drying apparatus for drying small samples of rice.

fully observed for the principal characters. If a selection from the progeny of a hybrid is segregating, desirable plants or panicles are selected and sown in single-row plots the second year. When promising lines are breeding true to type, they are tested in replicated yield trials in the same manner as introductions. When a selection is proved to be outstanding, it is named, the seed supply is purified and increased, and it is released for commercial production.

Most of the varieties developed by the selection method have been replaced by newer varieties, although there are a few notable exceptions. In 1963, Bluebonnet 50 was the leading variety in the South, and Rexoro was grown rather widely in Louisiana and Texas. Caloro was the leading variety in California, and Colusa also was widely grown in that State.

Hybridization

Varieties developed by the selection method were a vast improvement over the varieties they replaced, but varieties developed by this method did not have all the desired characters. Since about 1922 rice breeders in the United States have used the hybridization method of rice breeding, and hundreds of crosses have been made.

Three systems are followed in the hybridization method of breeding rice. These are: (1) Two varieties are crossed and the progeny grown in pedigreed rows or bulk plots until pure lines are selected; (2) the backcrossing system in which two varieties are crossed and the F_1 plants crossed to one of these varieties and repeated for four or five times; and (3) the multiple crossing system in which four or eight varieties are crossed in pairs, followed by crossing the F_1 plants from the different combinations so that after two or three rounds of crossing, F_1 plants are obtained that contain some genes from each of the parent

varieties, These systems may also be modified in various ways.

CROSSING TECHNIQUES.—The two basic techniques used for making rice crosses are the clipping and the hot water method. There are several modifications of the clipping method but in each case a part of the lemma and palea is removed. In the hot water method the panicle is emersed in hot water.

An example of the clipping technique that has been widely used was described by Jones (55) and may be summarized as follows: In the morning before the rice begins to bloom, or in the afternoon after the daily blooming period has passed, all except 10 to 20 spikelets are removed from the female panicle. The upper part of the lemma and palea of the remaining spikelets are clipped off at about a 45° angle. This removes about half of the lemma but only the tip or none of the palea so the anthers can be easily removed with fine-pointed forceps. The emasculated panicle then is tagged and covered with a glassine bag. The same day or the next day between 9:00 a.m. and 2:00 p.m., depending somewhat upon the weather, the emasculated panicles are pollinated. Plants of the variety to be used as the male parent are examined, and a panicle that has spikelets about to bloom is taken. A spikelet that has the anthers pushing up toward the tip of the floret is opened, and an anther or two are placed in the emasculated flower. Usually the anthers are broken open and the pollen is dusted on the stigma. This process is repeated until all flowers have been pollinated. After pollination, the panicle is again enclosed in the bag and the designation of the parents and the date of pollination are written on the tag.

A modification of the clipping method has been used at the Rice-Pasture Research and Extension Center, Beaumont, Tex. In this method, the tips of the lemma and palea are clipped off at right angles to the longitudinal axis of the spikelet. The anthers then are removed by vacuum, by means of a fine glass nozzle connected to a vacuum pump that is driven by an electric motor operating from a storage battery. Emasculating is done in the early morning or in the late afternoon; and pollinating, bagging, and tagging are completed in the same manner as in the clipping method described by Jones (55).

Another technique that has been used for crossing rice is a modification of a method developed for wheat and barley (85). In this method, the lemma and palea are clipped at right angles to the longitudinal axis of the spikelet at a point just above the tip of the stigma. This cuts the anthers, and it is not necessary to remove them. The florets are clipped early in the morning or in the afternoon, and then the emasculated panicle is covered with a fairly large glassine bag. Later

that day or the next day, pollen from a male panicle that has many florets just starting to bloom is dusted on the stigmas of the emasculated panicle. Before pollination the bottom of the inverted bag on the emasculated panicle is slit so that it can be spread open and can serve more or less as a funnel while the pollen is being applied. The bag then can be closed, folded over, and fastened with a paper clip. The pollinated panicle is then tagged to show the designation of the parents and the date of pollination.

As a result of the elevated temperature within the bag, seed set may be poor in crosses made by clipping the floret. In an effort to devise a technique for making a cross that would not require bagging the female panicles, Jodon (39) developed the hot-water method for emasculating rice flowers. In this method, the female panicle is immersed in water at a temperature of 40° to 44° C. for 10 minutes in the morning before any of the florets have opened. This critical temperature renders the pollen grains ineffective but does not prevent the normal functioning of the female portion of the rice florets. Within a few minutes after the panicle is removed from the warm water, the florets that would have bloomed later that day open. These florets can be pollinated in the same manner as in the clipping method. Spikelets that already have been pollinated and spikelets that do not open are clipped off. Spikelets at the base of the panicle usually are immature and can be left to produce mother seed. It may not be necessary to bag the panicle, because the lemma and palea usually close in about 45 minutes. Thus, they usually are closed before other plants start to shed pollen. The pollinated panicle then is tagged to show the designation of the parents and the date of pollination.

SINGLE CROSSES.—The crossed seeds are planted in a greenhouse in the fall after the cross is made or in the field the next spring. When the F₁ plants are grown in the greenhouse during the winter, a year is saved because the F₂ population can be grown in the field the year after the cross is made.

Usually several F₁ plants are grown to assure that typical parental strains were used in making the crosses. The cross should be made so that the F₁ plant can be distinguished from the female parent variety. For example, when pubescent × nonpubescent varieties are crossed, the nonpubescent variety should be used as the female parent. F₁ plants should be propagated vegetatively until it is known that they are not needed for additional seed production or other purposes. Vegetative propagation of F₁ plants is also helpful in obtaining increased quantities of F₂ seeds.

Seeds from the F₁ plants are spaced thinly or space sown in rows 12 inches or farther apart. When space sown, seeds are placed 3 to 6 inches

apart in the row, so the F_2 plants can be examined individually for plant characters and disease reaction. A further advantage of space seeding F_2 populations is that all the seed produced by a selected F_2 plant can be harvested and used for (1) preliminary quality tests on milled samples (5 to 10 grams), (2) growing at different locations or dates of seeding to obtain information on reaction to diseases and to photoperiod and other environmental influences, and (3) seedling tests in greenhouse or growth chamber for blast reaction and seedling hardiness. In important crosses where known genetic variables can be identified, early-generation testing has proved very effective.

The rice-breeding procedures used in the F_3 and subsequent generations usually are governed by particular circumstances such as available personnel, physical facilities, financial considerations, urgency of a particular development, number of characters involved, and mode of inheritance.

The pedigree system has been more widely used than other systems of handling hybrid progenies, although modifications of the pedigree and bulk systems are frequently followed.

In the pedigree system, the F_2 plants are carefully examined in the field and laboratory. The selections that appear to be satisfactory for all characters studied are sown in individual rows (8 to 16 feet long and 12 inches apart) the next spring. Seeds are spaced thinly in rows. Space seeding is seldom used for F_3 and later generations.

When facilities and circumstances permit, a system of multiple screening of selections may be used. Desirable plants are saved from the F_2 progenies in the field, and each plant is threshed individually. A small portion of the grain of each is milled, and plants having chalky kernels are discarded. Milled samples from the remaining plants are tested in the laboratory to determine cooking quality. Undesirable plants are eliminated, and the seeds of each of those remaining after the double screening are divided into three parts. One part (about 25 seeds) of each is tested for reaction to hoja blanca under controlled conditions. Another part is seeded late in the field under conditions believed to be favorable for the development of blast. The third part is seeded in the breeding nursery to observe agronomic characters and to provide seed for further testing of lines surviving the multiple screening. This screening method eliminates many undesirable lines in the F_3 generation.

The F_3 lines are carefully examined throughout the growing season and usually from 6 to 15 panicles are selected from lines that have the desired plant and grain type and that appear to be resistant to diseases. The quantity of seed

from each panicle is seldom sufficient for seeding at more than one or two locations. Small samples for quality tests and a few seeds for disease nurseries may be obtained by bulking part of the seed from each of the 6 to 15 panicles harvested from a given F_3 line. The remaining panicles in a line may be harvested in bulk to provide additional seed for testing the line for resistance to straighthead, hoja blanca, and blast; and for seedling hardiness, grain quality, or other characters. The F_4 lines are handled in much the same manner as the F_3 lines. Usually from 3 to 6 selected panicles of each line are sown in panicle-row plots the following year.

Early-generation testing is continued until it is reasonably certain that the lines are no longer segregating for the characters under study. From 10 to 15 panicles are selected from non-segregating rows, and then the rows are harvested and threshed in bulk. Part of the seed from the harvested rows is used for more extensive laboratory grain quality tests.

Lines that have suitable grain type are then tested in a preliminary yield trial. Some lines may be discarded because of lack of vigor, weak straw, disease susceptibility, undesirable cooking quality, or other undesirable characters. Lines that are heterozygous for one or more characters but otherwise appear to be desirable are replaced by pedigree sublines selected from later generation panicle rows. True breeding lines usually can be isolated in six to eight generations. The true breeding lines then are tested for at least 3 years to determine yielding ability, disease resistance, time of maturity, plant height, stiffness of straw, and cold tolerance, and to check thoroughly milling, processing, cooking, and other characters. Lines that prove to be superior to existing varieties in one or more characters are then named, the seed is purified and increased, and the seed of the new variety is distributed to growers.

The bulk system has been used to a limited extent, particularly where time and space were limiting factors. True breeding lines usually can be obtained in fewer generations when the pedigree method is used.

In the bulk system of breeding, the F_1 plants are grown and the F_2 populations are sown in the same manner as in the pedigree method. The F_2 population is harvested and threshed in bulk. Progenies from each cross may be kept separate or the progenies from several crosses with similar parentage may be combined. From 10 to 25 rod rows are grown in F_3 . They are harvested and threshed in bulk and sown on a similar size plot the next year. This procedure is followed for each succeeding generation until F_6 or F_7 . In bulk-hybrid populations, special care should be taken to be sure that desirable plant types are not being eliminated through natural selection. For

example, tall and profuse-tillering types tend to eliminate short types (6).

The bulk system often is modified in various ways. For example, if there is a differential plant reaction to a natural or artificially induced infection of a serious disease, a bulk is made up by selecting the resistant plants. Plants that make up the bulk are sometimes tested for processing and cooking quality. Where the parents differ in grain type, panicles having the desired grain types are selected in bulk or the bulked seed is graded on the basis of length and width, and the desired grain type is saved. This operation might be repeated for several generations. When unfavorable weather or a shortage of help makes selections in the field impossible, a composite may be harvested and panicles selected in the laboratory. In this case, the grain from selected plants is combined for seeding the bulk plot the next year.

In California, progenies from each cross are sometimes grown in small, water-seeded plots where the material is seeded under conditions similar to those of the commercial ricefields. This method aids the breeder in selecting plants that emerge readily through deep water. Also, when rice is water seeded, some varieties do not develop sufficient roots, and plants may tend to lean as the grain matures. Thus, when rice is water seeded in breeding studies, plants may be evaluated for resistance to this type of lodging.

Each year the material may be subjected to natural selection pressures in an attempt to eliminate undesirable types. Examples of natural selection pressures are: Harvesting before late plants are mature if short-season types are desired; seeding under conditions where straight-head is likely to occur; or inoculating with *Aphelenchoides besseyi* Christie (sometimes called *A. oryzae* Yokoo) to eliminate plants susceptible to white tip. After six or seven generations, a large number of plants or panicles are selected, preferably from a space-planted population. The plants are carefully examined and only those that appear to have strong straw, disease resistance, and good grain type are selected. Seeds of the selections are then examined in the laboratory much the same as seeds from F_2 plants are examined, and those that appear to have the desired kernel characters are sown in single-row plots the next year. The selections are then handled in the same manner as advanced-generation selections obtained by the pedigree method.

Many rice varieties have been developed in the United States by the hybridization method. Varieties that were named and released are as follows: Arkrose, Belle Patna, Bluebonnet, Calady, Century Patna 231, Cody, Delrex, Gulfrose, Improved Bluebonnet, Kamrose, Lacrosse, Magnolia, Missouri R-500, Nato, Northrose, Nova, Prelude,

R-ID, Rexark, R-N, Saturn, Texas Patna, Toro, TP 49, and Vegold. Many of these varieties were not in commercial production in 1963, although varieties developed from crosses comprised about 85 percent of the United States acreage that year.

BACKCROSS.—The backcross system or a modification of the typical backcross system is successfully used to some extent in rice breeding in the United States. As with other small grains, this system is used when it is desired to transfer one gene or a small number of genes to a fairly well-adapted variety. This system has not been used as widely with rice as with other small grains. Commercial rice production methods in the United States have undergone periodic changes (combine harvesting, increased fertilizer use, new herbicides) that have resulted in rather drastic changes in plant-type requirements. Because rice breeders have had to search for divergent types, the use of standard varieties as recurrent parents in a formal backcross program has been prevented. As production methods become more stable and satisfactory plant types are developed, and as rice breeding progresses in the United States, the backcross method may be used more generally. Adair, Miller, and Beachell (7) described briefly the development of hoja blanca resistant, long-grain types by backcrossing.

Calrose (57), a medium-grain variety, was developed by this method of breeding.

MULTIPLE CROSS.—Multiple crossing has been used very little by rice breeders in the United States. Several varieties have been developed from rather complex crosses, but none of these were selected from a population obtained from systematically crossing four or more varieties.

Irradiation

Irradiation breeding has been employed in the United States. Several mutants that may be useful in breeding programs have been obtained in this manner, but no varieties have been developed.

Breeding for Agronomic Characters

Rice often is seeded early in the spring when the soil temperature is low, or it may be sown in water that is below the optimum temperature. Thus, seedling vigor is an important character of rice varieties, and it is desirable to study seedling vigor and cold tolerance concurrently and to combine the two characters in a rice variety.

At optimum temperatures, indica varieties generally grow faster in the seedling stage than do japonica varieties. However, some of the japonica varieties are more tolerant to low temperatures, and seedlings of these cold-tolerant japonica varieties may grow and develop faster than seedlings of indica varieties when the temperature of the soil or water is low.

Vigor and cold tolerance of seedlings are studied under controlled conditions (68) and in the field. In the controlled studies, the seeds are sown in water and the temperature is maintained at 60° F. The length of longest leaf at about 30 days is the criterion used to judge tolerance and vigor. The varieties and lines that are vigorous and cold tolerant under controlled conditions are tested in the field. Field experiments are conducted by water seeding in fields where the irrigation water is cold, or by drill seeding early in the spring. Because variability is high under field conditions, results for a particular experiment are not always dependable. But over a period of years, useful information can be obtained on the performance of varieties under these adverse conditions.

Varieties also differ in their response to low temperatures during the flowering stage. This character of rice varieties and breeding lines is studied by seeding late, so that pollen development and flowering occur when the temperatures are low. In Texas, when temperatures are below the optimum in October when rice is flowering, hardy varieties, such as Caloro, continue to develop; whereas cold-sensitive varieties, such as Bluebonnet 50 and Century Patna 231, may not produce seed.

Rice varieties also vary in response to high concentration of salts in the irrigation water and in the soil. Varietal response to salt was studied at Stuttgart, Ark., and Beaumont, Tex. At Stuttgart, on soils with a high salt content, Arkrose produced 4,180 pounds per acre and Bluebonnet 50 produced 3,172 pounds. On soils with lower concentration of salts, Arkrose produced 4,531 pounds per acre and Bluebonnet 50 produced 3,838 pounds. At Beaumont, with a concentration of sodium chloride of about 2,500 parts per million in the irrigation water, Caloro produced 1,789 pounds of grain per acre, whereas Toro produced only 842 pounds. When no salt was added to the irrigation water, Caloro produced 4,820 pounds per acre and Toro 3,716 pounds.

The Beaumont studies were conducted in 1/10-acre blocks of Beaumont clay soil. Approximately 2,500 parts per million of salt was maintained in the irrigation water by adding sodium chloride. Frequent additions of salt were needed because of dilution from rains and soil moisture exchange. As much as 15,000 pounds of salt per acre was used during the 70- to 80-day test. Salt was first added to the irrigation water when the rice plants were about 45 days old.

Under these conditions an attempt was made to grow breeding lines in single-panicle rows as well as to conduct yield tests in replicated nursery plots. Widely different responses occurred because of weather conditions during blooming and

immediately thereafter. When blooming occurred during periods of cloudy weather and moderate temperatures, practically all lines showed good seed sets. When temperatures were high and humidity was low, practically all lines showed poor seed sets. After several years, the test was abandoned because it required a great amount of time and effort and provided little information.

Varieties that produce maximum yields must have relatively short and sturdy straw, so that the rice does not lodge before harvest (fig. 17). Japonica varieties have smaller and shorter culms and shorter, narrower, and darker green leaves than do most indica varieties. Although there are exceptions, japonica varieties generally produce higher yields than do indica varieties; this indicates that morphologic characters might be associated with grain yield. The japonica varieties have tough but willowy stems. The less willowy straw character of the indica varieties is preferred since this type is less likely to lodge.

For several years, rice breeders have been searching for plants with short, slender stems; with erect, relatively narrow, dark-green leaves of intermediate length; and with low percentages of sterility at high rates of nitrogen fertilization. Strains approaching this description have been selected from crosses between a Taiwan variety, Tainan-iku No. 487 (P.I. 215,936),³ and United States varieties. Ten short-stature selections from these crosses were grown in a variety-fertilizer test in 1961. They averaged 4,224 pounds of rough rice per acre at the 160-pound nitrogen rate and 3,367 pounds at the 80-pound rate. The highest yielding strain yielded 5,658 pounds at the 160-pound rate and 4,022 pounds at the 80-pound rate, compared with Bluebonnet 50, an indica type variety, which yielded 3,448 and



FIGURE 17.—A field of Caloro rice showing serious lodging.

³ P.I. refers to the accession number assigned to foreign introductions by the Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture.

2,916 pounds, respectively, at the two rates of nitrogen fertilization.

In an effort to find short-stature types possessing superior yielding capacity, varieties that combine extremely narrow and erect leaves and small stems have been crossed.

Short-stawed plants have been found in hybrid and irradiated populations, as mutations from varieties, and in introductions from foreign countries. In Arkansas, naturally occurring dwarf types were saved from C.I. 9187,⁴ a high-yielding, lodging-resistant, early long-grain experimental variety that has short straw and narrow leaves. Crosses were made with Bluebonnet types to improve milling quality, and dwarf and semidwarf types were saved for testing.

The short-stature types showed considerable variation in plant height because of the degree of internode elongation. Club and grassy dwarfs seldom grow more than 12 to 18 inches tall. Since grains are shortened and frequently are otherwise distorted, they are of no economic value. Some intermediate-height, dwarf-type lines exhibit varying degrees of grain distortion. Other intermediate-height, dwarf-type lines appear to produce grains of normal size and shape.

All of the dwarf-type plants examined appeared to have the normal number of nodes. The reduced height was governed by the extent of internode elongation, including the peduncle (internode just below panicle). In all but one dwarf-type selections examined, all internodes of the stem, including the peduncle, showed reduced elongation when compared with normal height plants. An exception to this elongation pattern was observed in a dwarf plant selected at Beaumont, Tex., in 1955, from an irradiated population of Century Patna 231. The panicles of this selection were normal in length and floret number, and the peduncles were of about normal length. The lower internodes showed only minor elongation; this resulted in an extremely short and sturdy plant.

The grains of the dwarf were of normal length but appeared to be slightly tapered. This dwarf was crossed with normal Bluebonnet 50, Century Patna 231, Rexoro, and Texas Patna. Dwarf-type selections resembling the original strain were recovered in about a 3 normal:1 dwarf-type ratio in all crosses. The original and the dwarf-type selections from the crosses were tested in yield experiments and invariably showed about 15- to 20-percent lower yields than did normal strains. All the dwarf-type strains showed considerably more sterility than did the normal strains, which was probably responsible for the reduced yields.

⁴C.I. refers to the accession number used in the Cereal Crops Research Branch, Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture.

The cause of the increased sterility was not determined. This promising dwarf type will be studied further.

Generally a high rate of nitrogen fertilizer is applied to rice-breeding nurseries to select types that respond to fertilizer and that resist lodging. When pure lines are isolated, they are then tested at two rates of nitrogen fertilization. Usually a randomized, split-plot design is used with varieties as the main plots and with nitrogen rates as subplots (fig. 18).

At Stuttgart, Ark., a continuing experiment designed cooperatively by the agronomist, the plant breeder, and the plant pathologist has been established to compare outstanding experimental varieties with commercial varieties they might be expected to replace. Varieties are tested in maturity groups and receive nitrogen fertilizer at a number of rates and times. The varieties are checked closely for grain yields and disease reaction, lodging, and other characters in the field. Milling yields and chalkiness of the grain and kernels resulting from the various treatments are also checked. To develop a satisfactory nitrogen fertilization program for each variety so that it will give consistently high grain yields with a minimum of lodging and disease, possible new varieties are tested 2 or 3 years as part of a final evaluation before their release.

In fertilizer-variety tests at Stuttgart, Ark., C.I. 9434, a very short-season, experimental long-

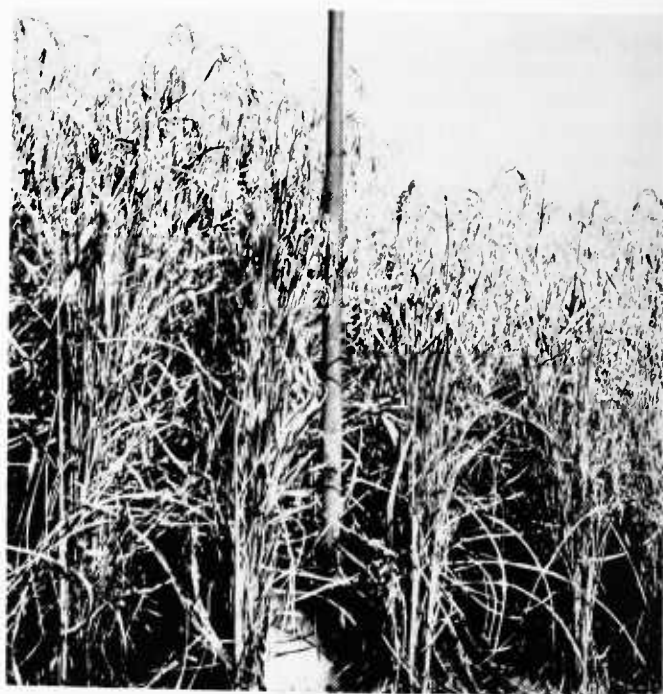


FIGURE 18.—C.I. 9446 fertilized at two rates: *Left*, 200 pounds of nitrogen per acre produced a yield of 5,707 pounds of rice per acre; *right*, 40 pounds of nitrogen per acre produced 3,942 pounds of rice per acre.

grain variety, produced 5,992 pounds of grain per acre compared with 5,839 pounds produced by Bluebonnet 50. In both tests the treatment included 200 pounds of nitrogen per acre, but C.I. 9434 produced this relatively high grain yield in 45 days less time than did Bluebonnet 50; and the straw of C.I. 9434 was 14 inches shorter.

The results from these experiments indicate that it will be possible to develop short-strawed, nonlodging varieties that respond to high rates of fertilizer. Notes on breeding lines and strains in yield tests recorded about 30 and 60 days after seeding and at maturity provide valuable information on plant type. By using symbols, brief notes are obtained on (1) habit of growth of leaves (erect to spreading); (2) color of leaves (light to dark green); (3) leaf width (narrow to wide); (4) plant or seedling height (short to tall); and (5) degree of tillering (low to high). Calculating sterility percentage by counting the number of sterile and fertile florets on selected panicles of breeding lines appears to have merit.

The grain yield of breeding lines and experimental varieties is determined by using replicated nursery plots. For comparison, standard varieties are included in each trial. The experimental design is a complete randomized block, usually with four replications. The plots are about 1 rod (5 meters) long and three or four rows wide. Usually the rows are spaced 9 inches apart in the 4-row plot or 12 inches apart in the 3-row plot. The plots are trimmed to a uniform length before harvesting. For yield determination, the center row is harvested in the 3-row plot, and the two interior rows are harvested in the 4-row plot. One or both of the border rows may be harvested in order to have a larger sample for milling and cooking tests.

An alternate method is the use of 4-row plots usually 15 or 16 feet long with a 12-inch spacing between rows. An 8-foot segment from the two center rows is harvested. By careful harvesting, the remainder of the plot is left standing for later observations and for collection of panicle samples.

In California, where the rice on all farm fields is sown broadcast in the water, the method used for testing varieties is somewhat different. The rice is sown in the water by hand.

The design used for preliminary trials is a complete randomized block with three or four replications. The individual plots are a single row, 12 to 16 feet long, with the rows spaced about 24 inches apart. The preliminary trial gives information on the ability of the variety to emerge through the water, straw strength, and other characters. The best varieties then are tested in randomized, quadruplicated plots large enough to be harvested with a small combine.

Time of maturity (length of growing season) is an important consideration in the breeding pro-

gram. Although early and very early types have gained favor in recent years, a complete range of maturity types is maintained.

Partial dormancy in rice is desirable, so that rice does not germinate if rain and humid weather occurs at harvesttime or if plants are badly lodged. Seed of nondormant varieties will germinate before cutting if there is a prolonged period of rain after the grain is ripe. It sometimes is desirable to break dormancy of seeds soon after harvest. This is necessary in the case of crossed seeds to be planted in the greenhouse in the winter or other breeding material to be grown during the off season in another region. This can be done by treating in a 0.10- to 0.05-percent solution of sodium hypochlorite for 24 hours or by heating in shallow, open containers for 3 to 5 days at 47° to 50° C.

Rice varieties in the United States are divided by grain size and shape into three types. These are short- (Pearl), medium-, and long-grain types. The more slender, long-grain varieties are sometimes considered as a fourth type. Examples of each type are Caloro, Nato, Bluebonnet 50, and Rexoro, respectively. The grain type can be visually classified; but for more critical comparisons of varieties and for classification, more exact measurements are needed. At the Cooperative Rice Quality Laboratory at Beaumont, Tex., the various grain types are characterized objectively according to length, width, length/width ratio, thickness, and grain weight. Dimensions of rough (paddy), brown, and milled (head) rice grains are measured and reported in accordance with the following definitions:

(1) Length of awnless rough rice is the straight-line distance (millimeter) from the point of disarticulation of the grain, which is below the outer glumes, to the tip of the apiculus (fig. 19, *B*). For awned rough rice the tip of the lemma is the reference point. Length for brown and milled rice is the distance between the most distant tips of the kernel, including the embryo of the brown rice kernel (fig. 19, *A*).

(2) Width (dorsiventral diameter) for rough rice is the distance (millimeter) across the lemma and palea at the widest point (fig. 19, *B*). Width for brown and milled rice is the distance across the kernel at the widest point (fig. 19, *A*).

(3) Thickness (lateral diameter) for rough rice is the distance (millimeter) from one outside surface of the lemma to its opposite at the thickest point (fig. 19, *D*). Thickness for brown and milled rice is the distance from one side of the kernel to its opposite side at the thickest point (fig. 19, *C*).

By modifying a photographic enlarger, a device was built for measuring the length and width of rice (fig. 20). The enlarger was mounted on a box with three sides that were painted black on

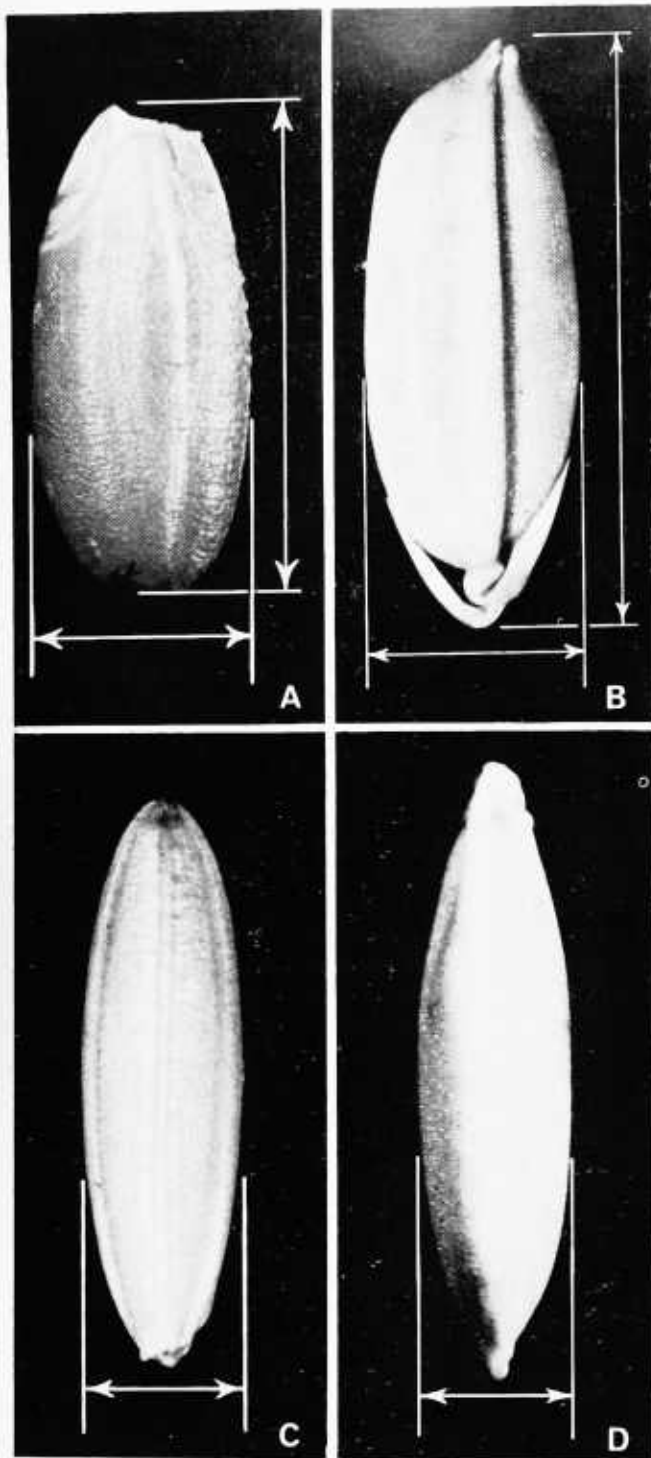


FIGURE 19.—Points from which rice grain and kernel measurement should be made.

the inside. A black cloth was placed over the open side of the box to exclude most of the light, so that a distinct image of the rice grain would appear on the white grid. Minute adjustments were made to obtain a magnification of exactly 10 times.



FIGURE 20.—Device for measuring rice grains and kernels.

The light source was a 6- or 12-volt cold, sealed-beam, automobile spotlight. The spotlight had a smooth surface, so that light or shaded areas would not be projected on the grid. Any cold light source of similar intensity should be satisfactory.

A 50-mm.F/4.5 liminized lens was used. This lens made it possible for the enlarged image ($10\times$) to be projected on a grid that was less than 24 inches from the lens.

A glass slide that held 10 grains was placed in the light field just above the bellows and the 50-millimeter lens. A millimeter scale was placed on the glass slide. The image of the millimeter scale was magnified 10 times and made possible accurate focusing before use. The adjustable bellows to which the 50-millimeter lens was attached made it possible to obtain a clear-cut image. The enlarged images of the rice grain were measured to obtain the length and width.

The thickness of the rice grain was determined by using a micrometer caliper graduated in millimeters. The micrometer was placed in a small vice attached to a table. A sheet-metal tray at the base of the micrometer, to catch grains dropped during the operation, is useful.

If similar equipment is not available, a random sample of 10 grains or kernels can be placed adjacent on transparent tape in the desired position for the particular measurement, and the total length, width, or thickness can be measured with a fair degree of accuracy by using a transparent ruler.

The length, width, and thickness of milled kernels are determined by measuring 15 whole kernels selected at random from a representative sample. The coefficient of variation for each dimension is calculated for each of 15 kernels to determine the uniformity of size and shape. Size and shape classes for brown kernels are as follows:

<i>Size classification</i>	<i>Length (Millimeters)</i>
Extra long (EL) -----	Over 7.5
Long (L) -----	6.61 to 7.5
Medium (M) -----	5.51 to 6.6
Short (S) -----	Up to 5.5

<i>Shape classification</i>	<i>Length/ width ratio</i>
Slender -----	Over 3
Medium -----	2.1 to 3
Bold -----	Up to 2.1

The average length, length/width ratio, thickness, and 100-grain weight of rough, brown, and milled (head) rice for each of 18 varieties are tabulated in table 6.

Testing for Milling, Cooking, and Processing Qualities

The determination of milling, cooking, and processing qualities of hybrid progenies, breeding lines, and new varieties is an essential part of the rice-breeding program. New varieties that are released for commercial production must meet established standards for these qualities. Certain cooking and processing qualities are historically associated with specific grain types. For example, most of the long-grain varieties grown in the United States cook dry and flaky, and some are used for specific processed products. The short- and medium-grain varieties grown in the United States are more moist when cooked than are the long-grain varieties and are used for specific processed products such as dry cereals. Thus, it is desirable that a new variety have the same cooking and processing qualities as the variety it replaces.

Milling Quality

The objective of rice milling is the removal of hulls, bran, and germ with a minimum breakage of the endosperm. The milling process generally consists of four fundamental operations: (1) Cleaning the field-run rough rice to remove such things as mud lumps, rice stems and leaves, weed seeds and stems, and other foreign matter; (2) shelling the cleaned rice to remove the hulls; (3) scouring the brown rice to remove the coarse outer layers of bran, white inner-bran, aleurone layers, and germ; and (4) grading the mixture of whole and broken milled kernels according to size classes known as head rice (whole-grain milled kernels), second head (larger pieces of broken milled kernels), screenings (smaller pieces of broken milled kernels), and brewers rice (very small pieces of broken milled kernels) (7, 16). In modern rice mills, all operations in the rice-milling process are performed mechanically with a minimum amount of manual labor, including the transfer of rice from one machine to another for the next series of operations. Fraps (30), Geddes (31, pp. 2043-2051), Kik and Williams (62), Wayne (84), and, more recently, Kester (61) have described the commercial milling of rice as practiced in the United States. Additional information describing rice milling and processing equipment has been published by the Food and Agriculture Organization of the United Nations (9, 24).

The milling quality of rice is based on the yield of head rice obtained, since it is usually the milled product of the greatest monetary value. Yields of head rice vary widely, depending on variety, grain type, cultural methods and other environmental factors, and the drying, storing, and milling conditions. The yield of total milled kernels (head rice and all sizes of broken kernels) is important, too, and this yield is influenced by the proportion of hulls and the amount of fine particles of broken kernels unavoidably included in the bran fraction during the milling process.

In rice-breeding programs, rigid laboratory milling tests are required to insure that any new variety released will consistently produce high yields of head rice and total milled rice. At the

TABLE 6.—*Grain characters for 18 rice varieties grown in Uniform Yield Nurseries in Arkansas and Texas, 1959-61*

[Values are averages and are for first cutting only]

Grain type and variety	Grain form ¹	Grain characters			
		Length	Ratio L/W	Thickness	100-grain weight
		<i>Millimeters</i>		<i>Millimeters</i>	<i>Grams</i>
Short-grain :					
Caloro -----	Rough -----	7.3	2.0:1	2.3	2.8
	Brown -----	5.4	1.7:1	2.1	2.3
	Milled -----	4.9	1.8:1	2.0	2.2
Cody -----	Rough -----	7.1	1.9:1	2.5	2.8
	Brown -----	5.4	1.7:1	2.1	2.3
	Milled -----	5.0	1.7:1	2.0	2.2
Colusa -----	Rough -----	7.2	1.9:1	2.3	2.8
	Brown -----	5.4	1.7:1	2.0	2.3
	Milled -----	5.0	1.8:1	1.9	2.2
Medium grain :					
Arkrose -----	Rough -----	8.4	2.6:1	2.2	3.1
	Brown -----	6.3	2.3:1	1.9	2.4
	Milled -----	5.8	2.2:1	1.8	2.2
Calrose -----	Rough -----	7.8	2.4:1	2.1	2.5
	Brown -----	5.9	2.2:1	1.8	2.0
	Milled -----	5.6	2.3:1	1.8	1.9
Gulfrose -----	Rough -----	8.0	2.5:1	2.0	2.5
	Brown -----	6.3	2.3:1	1.8	2.0
	Milled -----	5.8	2.3:1	1.7	1.9
Magnolia -----	Rough -----	8.3	2.5:1	2.1	2.6
	Brown -----	6.3	2.3:1	1.8	2.1
	Milled -----	5.9	2.3:1	1.7	2.0
Nato -----	Rough -----	7.3	2.4:1	2.0	2.1
	Brown -----	5.8	2.2:1	1.7	1.7
	Milled -----	5.3	2.2:1	1.6	1.6
Northrose -----	Rough -----	7.7	2.4:1	2.1	2.4
	Brown -----	5.8	2.1:1	1.9	1.9
	Milled -----	5.4	2.2:1	1.7	1.8
Zenith -----	Rough -----	7.8	2.4:1	2.0	2.3
	Brown -----	6.0	2.3:1	1.7	1.8
	Milled -----	5.7	2.3:1	1.6	1.7
Long-grain :					
Belle Patna -----	Rough -----	8.7	3.7:1	1.8	2.1
	Brown -----	6.8	3.4:1	1.7	1.7
	Milled -----	6.5	3.4:1	1.6	1.6
Bluebonnet 50 -----	Rough -----	9.6	3.8:1	1.9	2.5
	Brown -----	7.2	3.4:1	1.7	2.0
	Milled -----	6.8	3.4:1	1.6	1.8
Century Patna 231 -----	Rough -----	9.1	3.9:1	1.8	2.1
	Brown -----	7.0	3.4:1	1.6	1.6
	Milled -----	6.5	3.4:1	1.6	1.5
Rexoro -----	Rough -----	8.8	3.9:1	1.7	2.1
	Brown -----	7.1	3.6:1	1.6	1.7
	Milled -----	6.5	3.5:1	1.5	1.5
Sunbonnet -----	Rough -----	8.9	3.6:1	2.0	2.4
	Brown -----	7.2	3.3:1	1.8	1.9
	Milled -----	6.7	3.3:1	1.6	1.8
Texas Patna -----	Rough -----	9.1	4.0:1	1.7	2.0
	Brown -----	7.1	3.6:1	1.5	1.6
	Milled -----	6.6	3.6:1	1.5	1.5
Toro -----	Rough -----	9.0	3.8:1	1.9	2.2
	Brown -----	7.1	3.4:1	1.7	1.7
	Milled -----	6.5	3.3:1	1.5	1.6
TP 49 -----	Rough -----	9.4	4.0:1	1.8	2.2
	Brown -----	7.3	3.7:1	1.6	1.8
	Milled -----	6.7	3.6:1	1.6	1.7

¹ Rough = unhulled grain; brown = grain with hull removed; milled = whole grain milled kernels with hull, bran, and germ removed.

Cooperative Rice Quality Laboratory at Beaumont, Tex., three methods are available for estimating the milling quality of rice varieties and selections. The method used depends on the amount of rice available for testing. The official grading method for determining the milling quality of rough rice by United States standards, described by Smith (78, 79, 80, 81) and adapted to laboratory conditions, gives the breeder comparative information regarding milling quality of the more advanced selections grown in larger plots. The method requires 1,000 grams of rough rice for each determination.

A modification of the official method requires only a 125-gram sample (19) to estimate the milling quality of rice and enables the breeder to check milling quality at very early stages of selection. The samples of rough rice are sealed in glass jars and kept at room temperature for at least 24 hours to bring the moisture content to equilibrium before the rice is milled. The moisture content is determined, a 125-gram sample of the rice is hulled in a McGill sheller, and the brown rice is weighed. The weight of the hulls is determined by subtracting the weight of the brown rice from the weight of the rough rice.

The brown rice sample is milled in a small McGill miller for 30 seconds, using a 14-pound weight over a steel plate that covers the rice. The sample is immediately milled a second time for 30 seconds, using a 4-pound weight. This second milling gives a high polish to the rice kernels but causes little additional breakage. The milled kernels are sealed in a glass jar to prevent unnecessary breaking due to rapid or uneven cooling. The bran is screened through a 20×20 mesh wire screen to recover the small, broken kernels that passed through the miller screen. The finely broken kernels thus recovered are aspirated and added to the milled kernels. The milled kernels are weighed when the rice has cooled to room temperature. The weight of the bran and polish is the difference between the weight of brown rice and the weight of total milled rice.

The whole kernels are separated from the total milled portion with a sizing device developed by the Grain Division, Consumer and Marketing Service, U.S. Department of Agriculture. This device makes use of two indented plates, with flat-bottom holes, tilted at a slight angle and shaken by an eccentric mechanism. During the shaking motion, the rice travels the length of the top sloping plate and drops onto the bottom sloping plate. Whole kernels drop off the end into a container; broken kernels fall into the indents in the plates. Plates with specific size indents are used for each grain type. Results usually are reported as percentage of hulls, bran, head rice, and total milled kernels.

A method also is available for milling very small samples of rice (76). This method can be used to mill the rice from one panicle. The rough rice sample is thoroughly cleaned and hulled in a McGill sheller, and a 5-gram sample is weighed for milling. The weighed sample is put into a test tube with 3 grams of abrasive (40- to 60-mesh fused white aluminum oxide or clean, sharp, white quartz sand). The stoppered test tube is mounted in the test-tube miller, which holds 80 test tubes, and is shaken for 45 minutes at a speed of approximately 390 strokes per minute. The samples then are removed and polished in a small sample polishing machine (77). This method of milling small samples not only gives information on the milling quality of individual plant selections but also provides a milled sample to use for preliminary tests of the physical and chemical properties of the kernel.

The average milling yields of hull, bran, total, and head milled kernels for each of 18 varieties grown in the Uniform Yield Nurseries in Arkansas, Louisiana, and Texas from 1958 through 1961 are tabulated in table 7. Estimated yields were determined according to the modified procedure of Beachell and Halick (19).

Cooking and Processing Qualities

Rice varieties differ greatly in cooking and processing qualities. Among the domestic varieties the quality of home-cooked rice has been described as varying from very sticky to flaky (46). Fully cooked grains of typical United States short- and medium-grain varieties are usually somewhat sticky, relatively firm, and tend to stick together. Typical long-grain varieties usually cook to a flaky state with a minimum of splitting and do not tend to stick together. Other terms used to subjectively describe cooking quality are moist or dry, soft or firm, and mealy or chewy. Since different cultural groups prefer different textures, there is a rather widespread demand for all types for use as home-cooked table rice.

There is also a demand for all types of rice for use in the widely different prepared products. Processors of rice prefer different textures for their various products and also specific qualities adapted to the processes themselves. According to Kester (61), a substantial amount of the domestic rice crop is processed into various kinds of prepared foods such as parboiled rice, quick-cooking rice, breakfast cereals, canned rice, canned soups, canned rice and vegetable mixtures, dry soup mixes, enriched baby foods, and frozen dishes. Rice flour is used in various processes, and broken rice is often used in brewing. Typical long-grain varieties are preferred for many parboiled and quick-cooking products, and specific

TABLE 7.—*Milling yields for 18 rice varieties grown in Uniform Yield Nurseries in Arkansas, Louisiana, and Texas, 1958-61*

[Values are averages and are for first cutting only]

Grain type and variety	Milling yields ¹				
	Milled rice			Head rice	
	Hulls average	Bran average	Total average	Average	Range
	Percent	Percent	Percent	Percent	Percent
Short-grain:					
Caloro -----	18	9	73	68	58-72
Cody -----	19	9	72	67	58-71
Colusa -----	18	9	73	65	42-75
Medium-grain:					
Arkrose -----	20	9	71	63	33-70
Calrose -----	19	10	71	69	63-72
Gulfrose -----	20	10	70	65	58-70
Magnolia -----	20	9	71	66	63-72
Nato -----	19	9	72	68	63-73
Northrose -----	20	12	68	64	59-69
Zenith -----	20	10	70	64	53-71
Long-grain:					
Belle Patna -----	19	11	70	60	50-69
Bluebonnet 50 -----	19	11	70	63	52-68
Century Patna 231 -----	21	12	67	62	50-67
Rexoro ² -----	19	13	68	52	36-61
Sunbonnet -----	19	10	71	62	50-71
Texas Patna ² -----	19	13	68	58	48-65
Toro -----	19	10	71	67	60-70
TP 49 ² -----	19	11	70	58	52-62

¹ Total milled rice is the head rice and all sizes of broken kernels. Head rice is the whole grain milled kernels.² Grown only in Louisiana and Texas.

long-grain varieties are preferred for certain canned soup products. Medium- and short-grain varieties are more suitable for dry breakfast cereals and for use in baby foods and in brewing. The short-grain types exclusively are used for making puffed rice.

Although in the United States each grain type is generally associated with specific cooking and processing qualities, notable varietal exceptions within each grain type have been reported; and the nontypical cooking and processing quality of these grain-type exceptions in relation to measured differences in some chemical and physical qualities of the rice grain has been discussed (20, 33).

In rice-breeding programs, cooking and processing quality is considered to be an important measure of the suitability of a variety or selection for specific purposes. At the Cooperative Rice Quality Laboratory at Beaumont, Tex., results of specific chemical and physical tests collectively serve as indices of cooking and processing qualities. The results guide the rice breeder in selecting lines that combine the desired cooking and processing qualities and agronomic features. The merit of this type of evaluation has been clearly demonstrated.

Some of the chemical and physical tests are the determination of amylose content (87), starch-iodine-blue value (34), gelatinization temperature (33), type and extent of disintegration of whole milled kernels in contact with dilute alkali (65), and amylograph pasting qualities (33).

The amylose content of rice, particularly of long-grain types, has recently been associated with cooking quality (71, 87). The investigations of Williams and others (87) showed that the long-grain domestic varieties known to cook dry-flaky usually had the highest amylose content; whereas the amylose contents of the short- and medium-grain varieties investigated were somewhat lower. The glutinous (waxy) varieties contain virtually no amylose. The simple, rapid, and somewhat empirical starch-iodine-blue test (34) is particularly useful in breeding programs for estimating the relative amylose content of early-generation breeding material.

The gelatinization temperature of rice is believed to be closely related to cooking quality. The amylograph studies (33) showed that most short- and medium-grain varieties gelatinized at lower temperatures than did most of the long-grain varieties investigated. These results were confirmed by granule swelling and birefringence

end-point temperature (BEPT) determinations (32).

The reaction of milled rice kernels in contact with dilute alkali has been used to classify the cooking quality of rice (56, 83). The type and extent of disintegration of whole milled rice kernels in contact with dilute alkali were reported more recently (65). Two distinct reactions were noted: (1) Spreading where the kernels disintegrated into small granules and spreading to several times the original kernel size; and (2) clearing where the starch is solubilized with a loss of opacity. Spreading and clearing were evaluated on a numerical scale from 1 (minimum) to 7 (maximum). A slight-to-moderate reaction was characteristic of most domestic long-grain varieties and a more pronounced reaction was characteristic of most short- and medium-grain varieties. A very high correlation between the alkali reaction and gelatinization temperatures has been observed (33).

The pasting quality of several domestic varieties as determined with the amylograph have been described (33). In general, amylograph curves of rice varieties were typical of those of other cereal starches, but they showed appreciable differences among the varieties studied. Long-grain varieties with the highest amylose content usually showed the greatest increases in viscosity when cooled to 50° C. Amylograms of most short- and medium-grain varieties generally exhibited relatively shorter gelatinization times.

Notable varietal exceptions within each grain type were observed by Halick and Kelly (33). For example, the long-grain varieties Rexark and Toro had amylose contents, gelatinization temperatures, and alkali spreading and clearing reactions similar to those of typical short- and medium-grain varieties. These long-grain varieties are also thought to resemble the typical short- and medium-grain varieties more in cooking quality than they do other long-grain varieties. Of all the varieties tested, Century Patna 231, a long-grain variety, and Early Prolific, a medium-grain variety, had the highest gelatinization temperature and were the most resistant to the action of dilute alkali. In general, these varieties have not been widely accepted for certain types of cooked rice and processed products.

Average values for some of the physical and chemical characters of 18 rice varieties grown in the Uniform Yield Nurseries in Arkansas, Louisiana, and Texas, from 1958 through 1961, are tabulated in table 8. Environmental and other factors influence these qualities to some extent; however, within a limited range, the values are representative of each variety. In the rice-breeding program, characters of new selections are always compared with comparably grown commercial varieties. Some of the physical and chemical

characters of the short- and medium-grain varieties listed in table 8 are a relatively low amylose content, a relatively low gelatinization temperature, a very pronounced alkali reaction, and a relatively low viscosity of the cooked paste when cooled to 50° C. The typical long-grain varieties are qualified by a relatively high amylose content, an intermediate gelatinization temperature, a slight-to-moderate alkali reaction, and a maximum increase in viscosity of the cooked paste when cooled to 50° C. Of the typical long-grain types, the late-maturing varieties Rexoro, Texas Patna, and TP 49 consistently had the highest amylose content, the lowest peak viscosity, and a maximum viscosity of the cooked paste when cooled to 50° C. These varieties are preferred for certain canned soup products. The non-typical cooking and processing quality of Century Patna 231 and Toro, both long-grain varieties, has been discussed previously.

Physical and chemical grain quality evaluation tests are invaluable to the plant breeder in developing varieties with specific processing and cooking quality. The specific tests used depend on the quality variables of the particular hybrid population in question and the purpose for which the end product is to be used.

The results of the starch-iodine-blue and the alkali digestion tests enable the plant breeder to classify early-generation hybrid lines as to gelatinization temperature of starch and relative amount of amylose. Promising advanced-generation lines are evaluated from data obtained in analytical tests for amylose and protein content, pasting qualities using an amylograph, and cooking, parboiling, and canning tests. In certain crosses where it is essential to retain a specific pasting quality or parboiling and canning character, it may be necessary to obtain amylograph data on early-generation lines to make certain that the desired qualities are recovered. Such tests are usually conducted on a relatively small number of samples because of the quantities of grain required and the time used in performing the tests. Parboiling and canning tests using 5 to 10 grams of rough rice can be conducted on rather large numbers of samples if necessary, but the cost is relatively high.

The cross Gulfrose × Bluebonnet 50 is an example of how quality tests aid in the rice-breeding program. In this cross, the objective was to develop a long-grain Bluebonnet 50 type possessing the hoja blanca resistance of Gulfrose. Gulfrose ordinarily shows a low gelatinization temperature and relatively low amylose content, whereas Bluebonnet 50 ordinarily shows intermediate gelatinization temperature and relatively high amylose content.

A large number of long-grain types resembling Bluebonnet 50 were saved from the F₂ plant

TABLE 8.—*Physical and chemical characters of milled kernels for 18 rice varieties grown in Uniform Yield Nurseries in Arkansas, Louisiana, and Texas, 1958-61*

[Values are for first cutting only]

Grain type and variety	Physical character (paste viscosity) ¹		Chemical characters			
	Peak	Cooled to 50° C.	Amylose content ²	Gelatiniza- tion tempera- ture ²	Alkali reaction ³	
					Spreading	Clearing
	<i>Brabender Units</i>	<i>Brabender Units</i>	<i>Percent</i>	<i>° C.</i>		
Short-grain:						
Caloro	850	690	19	66	7	6
Cody	950	690	17	67	6	6
Colusa	840	690	18	67	6	5
Medium-grain:						
Arkrose	820	660	21	64	7	6
Calrose	960	680	19	65	7	6
Gulfrose	750	660	19	66	6	5
Magnolia	920	700	14	67	6	5
Nato	960	640	16	67	6	5
Northrose	820	630	15	67	6	5
Zenith	860	710	19	66	6	5
Long-grain:						
Belle Patna	820	770	26	70	4	2
Bluebonnet 50	790	730	24	73	4	2
Century Patna 231	950	730	16	77	2	1
Rexoro	600	750	28	69	4	3
Sunbonnet	810	740	26	73	4	2
Texas Patna	630	760	28	71	4	3
Toro	870	740	17	65	7	6
TP 49	690	770	28	69	4	3

¹ Average Uniform Yield Nursery in Texas, 1958-61.² Uniform Yield Nurseries grown only in Arkansas and Texas.³ Reaction in 2.0 percent potassium hydroxide solution.

population. A portion of the grain from each plant saved was milled in a test-tube miller. The milled samples were visually examined for grain texture, size, and shape; and alkali digestion and iodine-blue values were determined. Samples showing grains of intermediate gelatinization temperature and relatively high amylose (an iodine-blue value of 25 or below) were saved for hoja blanca testing. In the F_3 plant generation, a bulk made up of 15 or more panicles was again milled, and the quality tests were repeated. The strains that appeared satisfactory agronomically after F_5 or F_6 plant generations were increased for yield testing; and at this stage other quality tests for characters, such as analytical amylose and protein content and pasting viscosity, were made.

Breeding for Disease Resistance

The easiest, most practical, and least expensive way to control rice diseases is to use resistant varieties. Considerable research has been done in

the United States on the reaction of rice varieties to the various rice diseases and on developing resistant varieties. Much of this work has been reviewed (13, 14). The symptoms, control measures, and importance of the rice diseases occurring in the United States are given in the section "Rice Diseases," p. 113. Methods used to breed resistant varieties are presented in this section.

Certain basic principles apply to breeding for disease-resistant varieties of a crop. Techniques to create an epiphytotic of the disease and to evaluate and record the response of the plant to the causal organism must be developed. Then the available varieties and breeding lines must be tested to determine sources of resistance to the causal organism. Resistant varieties can then be crossed with varieties possessing other desirable characters, the progenies can be tested, and the resistant lines can be isolated. Where a resistant variety has few attributes other than resistance to the disease under study, it may be used as the donor variety in a backcross program. In order to develop efficient breeding techniques, the mode of inheritance of reaction to causal organisms must be determined.

Blast

Blast, caused by the fungus *Pyricularia oryzae* Cav., is an important disease of rice. Much research has been done on it in the United States and in other rice-producing countries. Physiological races of *P. oryzae* that occur in the United States (64) make the breeding of resistant varieties more complex than if races did not occur. Genes for resistance to each race that is known to occur in the United States are available, but not all are present in any one variety.

A satisfactory method for inoculating plants (8) and a system of rating reaction have been developed (64). Many varieties in the World Collection and breeding lines have been tested under controlled conditions for reaction to specific races of *P. oryzae*. Uniform trials have been conducted in the field under a wide range of environmental conditions (13). Some studies on the genetics of reaction to *P. oryzae* have been made (13, 66), but information is not available on the genetics of reaction to all races.

An accelerated program of testing and breeding rice for resistance to blast in the United States was started in 1959. The initial tests consisted largely of screening in the greenhouse the more promising varieties and selections for reaction to races 1 and 6. Later, many other breeding lines from Arkansas, Louisiana, and Texas rice experiment stations were screened. Material grown in the field and harvested in the late summer or early fall is available for greenhouse testing from November through March.

The method used for developing blast-resistant varieties in the United States (13) is as follows:

(1) Seeds from F_3 or F_4 progenies of crosses between varieties possessing the desired resistance genes are saved.

(2) Seedlings from these progenies are inoculated in the greenhouse to determine reaction to race 6. Susceptible selections are not tested further.

(3) Seedlings that are resistant to race 6 are then inoculated in the greenhouse with race 1.

(4) Selections that carry resistance to races 1 and 6 are sown in the field for further evaluation of field and grain characters. Many of the less desirable lines are eliminated at this stage.

(5) Seedlings of the selected lines are inoculated in the greenhouse with races 1 and 6 to confirm results of previous tests.

(6) Selections that are resistant to races 1 and 6 then are inoculated with races 2 or 4, 7, 8, 16, and 19, as time and facilities permit.

(7) Selections that are resistant to all races are then grown in the field in observation rows or in yield tests for further evaluation as potential new rice varieties.

Selections that are resistant to the desired races

of blast but do not appear promising for developing an improved commercial variety are crossed with a suitable variety or strains. Testing for reaction to blast is then repeated. This operation may be repeated several times, or until suitable plant types occur.

Many breeding lines have been tested, and promising strains of all grain types have been developed to combine resistance to several of the more common races of blast found in the United States. In Arkansas, in greenhouse tests, Nova was resistant or moderately resistant to most of the races of blast. In field tests, it was considerably more resistant than was Nato. Nova was released in 1963 jointly by the Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture, and the Arkansas Agricultural Experiment Station (49).

Brown Leaf Spot

Brown leaf spot, caused by the fungus *Helminthosporium oryzae* B. de Haan, is a common disease of rice in humid areas. In 1941 a report was published (4) concerning the mode of inheritance of resistance to *Helminthosporium* in a cross of a moderately resistant and a susceptible variety. Inoculation with conidia was used to induce infection. All gradation from moderately resistant to susceptible occurred in the segregating populations. This indicated that the reaction was controlled by several genes lacking dominance.

The reaction of seedlings grown in the greenhouse showed a fairly close relationship with that of mature plants grown in the field and suggested the possibility of early elimination of a large proportion of susceptible segregates in breeding for resistance (4).

According to Nagai (66), he and Hara studied an especially susceptible mutant, and susceptibility proved to be due to a single recessive gene in crosses of a very susceptible and a normal plant.

A breeding program to develop varieties resistant to brown leaf spot was begun at Beaumont, Tex., about 1938. C.I. 9515, a resistant but agronomically undesirable strain selected from a cross made at Beaumont in 1938, was crossed with popular long-grain commercial varieties in 1945. Resistant selections from the 1945 crosses were crossed to commercial long-grain varieties in 1959. Selecting for resistance was started in the F_3 population by saving the more resistant plants in rows showing the best resistance, along with other desirable quality. A highly susceptible spreader variety was sown adjacent to each selection. Differences in disease reaction were relative and were more apparent between panicle rows than among individual plants. Resistance was based on the number and size of spots. The studies indicated that inheritance is not simple

and probably involves several genes. Selecting for resistance was continued through several generations or until apparent true breeding lines were established. Resistant lines possessing good agronomic characters were selected from the 1959 crosses.

Narrow Brown Leaf Spot

Narrow brown leaf spot, caused by the fungus *Cercospora oryzae* I. Miyake, is a common disease of rice in the Southern States. There are physiological races of the causal fungus (26, 73, 74, 75), but genes for resistance for each race are available. The mode of inheritance of reaction to *C. oryzae* has been studied (4, 45, 47). No linkage between genes for reaction to *Cercospora* and those for expression of five qualitative characters was found (45). Most of the work on the development of *Cercospora*-resistant varieties has been done in the field under conditions of natural infection. Selection is based on type of lesion and relative severity of infection. In Louisiana, a number of resistant selections were obtained when Blue Rose was crossed or backcrossed to Rexoro, although both parental varieties were susceptible to one or more races.

Straighthead

Straighthead is a physiological disease that occurs under certain environmental conditions in the United States. A breeding program to develop straighthead-resistant varieties was begun in the United States in 1953, at Eagle Lake, Tex. The method of testing consists simply of drill seeding the test entries in an area with a soil type, such as Hockley fine sandy loam, conducive to straighthead development and keeping the nursery test area continuously submerged after the initial irrigation (82). The reactions of the American rice varieties (11, 12) served as a basis for selecting parental varieties for resistance in a breeding program. Straighthead resistance is relative, and none of the varieties tested are immune or highly resistant. The resistance of Bluebonnet, Bluebonnet 50, Lacrosse, Prelude, and Toro is derived directly or indirectly from Fortuna, selected from the Pa Chiam variety obtained from Taiwan. C.I. 5094, selected from the Sinanpagh variety from the Philippines, served as the source of resistance in Texas Patna and the original Century Patna.

Testing selections from several crosses was begun in 1954. For example, straighthead-resistant selections were recovered from a cross of Bluebonnet (resistant) \times Century Patna 231 (susceptible) and from backcrosses to Century Patna 231. Although a number of the straighthead-resistant selections from the Century Patna 231 crosses were promising and were seriously

considered as new varieties, none were released. Belle Patna, from a different cross, was released as a new variety in 1961 (23). This variety has Bluebonnet as its source of straighthead resistance.

In the breeding program, straighthead-resistant selections have been obtained readily by selecting panicles from resistant or segregating lines for retesting in panicle rows. The number of genes involved in straighthead reaction was not established, but inheritance appeared to be relatively simple in crosses within the long-grain groups of varieties. Resistance seems to be dominant (12).

White Tip

White tip, first observed in Louisiana before 1930, was considered to be a physiological disease until 1949, when it was found to be caused by a seedborne, foliar nematode, *Aphelenchoides besseyi* Christie (27). However, by that time considerable progress had been made in selecting for resistance in nurseries in which the disease occurred rather consistently each year.

After white tip was found to be caused by a seedborne nematode, various methods were used to insure infection in order to determine the reaction of varieties and selections to white tip. These methods consisted of including heavily infested seed of susceptible varieties as spreader rows, using rice hulls containing large numbers of nematodes, or introducing nematodes from laboratory cultures into the irrigation water. Atkins and Todd (15) determined reaction of many rice varieties in the United States to white tip. No studies have been made on the genetics of inheritance.

Hoja Blanca

Hoja blanca is a virus disease of rice that occurs in the Western Hemisphere. In 1957, a large number of United States varieties and selections, as well as introduced varieties, were tested for hoja blanca reaction under conditions of natural infection in Cuba and Venezuela (10). On the basis of marked differences in disease reaction in the nursery tests, Arkrose, Asahi, Colusa, Lacrosse, Mo. R-500, and several experimental varieties were designated as sources of hoja blanca resistance for use in breeding.

Since both resistant and susceptible entries were found among a number of advanced-generation selections from two crosses having Lacrosse as one parent, it was concluded that the genes for resistance could be readily transferred in crosses. Other studies showed that resistance was genetically controlled and could be transferred to varieties of all grain types (22) and that resistance was dominant (21). Since 1957, other lines resistant to hoja blanca have been recovered from

several crosses between susceptible and resistant parents. Thus far, none have been released as varieties.

Gulfrose, released in 1960 as a hoja blanca-resistant variety (1, 28), was an increase of a selection rated as resistant in the 1957 and subsequent tests. Nova, released in 1963, also a hoja blanca-resistant variety (49), was an increase from a selection rated as resistant in early tests.

Testing and breeding for resistance to hoja blanca are being continued in cooperation with Government and private agencies in several Central and South American countries. Much of the testing of varieties and breeding lines for reaction to hoja blanca has been done under conditions of natural infection in the field. This work has been done in foreign countries where epiphytotics of the disease usually occur. Hybrid and backcross plants and progeny lines also are tested in the greenhouse where plants are inoculated with viruliferous vectors. Since resistance to hoja blanca is dominant, backcross plants that carry resistance can be identified in greenhouse tests. Backcross seeds are planted in the greenhouse or field. As soon as the plants tiller, they are divided and part of the plant is tested for reaction to hoja blanca. The reaction can be determined by the time the plant flowers, so that plants carrying resistance can be identified and used as parents in the backcross program.

The pedigree method, the backcross method, and a modification of these two methods were used in Texas to develop long-grain varieties resistant to hoja blanca. The material used in the pedigree method was obtained by crossing the long-grain variety Bluebonnet 50 and several promising long-grain hybrid selections with the hoja blanca-resistant varieties Gulfrose and Tainan-iku No. 487 (P.I. 215,936). The F_1 plants were grown in the greenhouse during the winter of 1957-58, and the F_2 populations were grown in the field during the summer of 1958. In the fall of 1958, the seeds from 353 carefully selected F_2 plants were saved. A few grams of grain from each selection were milled in a test-tube miller, and alkali digestion and iodine-blue tests were performed. In 1959, progenies from each F_2 plant were grown in Colombia, Cuba, and Venezuela to test their reaction to hoja blanca; at Eagle Lake, Tex., to test their reaction to straighthead; and in the nursery at Beaumont, Tex., to advance each selection on a pedigree basis and to select on the basis of plant type and vigor.

In 1960, scientists at Beaumont selected 507 panicles from the better F_3 lines grown in 1959. Seed from each of these selections was sent to Colombia for further hoja blanca testing and progeny of each was grown in the breeding nursery at Beaumont. About 20 panicles were har-

vested from each row, and this grain was used to determine the cooking and processing quality of the F_4 lines.

Excellent hoja blanca readings from Colombia were obtained on the F_4 lines tested in 1960, as well as the F_5 and F_6 lines tested in 1961 and 1962. Hoja blanca-resistant selections were tested further for reaction to straighthead at Eagle Lake, for reaction to blast of seedlings at Beaumont, and for quality behavior in the cooperative Rice Quality Laboratory at Beaumont.

In 1962, a number of the more promising strains carrying hoja blanca resistance were grown in advanced yield trials at Beaumont. From the crosses made in 1957, hybrid selections of early and midseason maturity and short-, medium-, and long-grain types that are promising for resistance to hoja blanca are now available for extensive testing.

In the modification of the backcross method used in the hoja blanca breeding program, the F_1 plant of the cross Bluebonnet 50 \times Gulfrose was backcrossed to Bluebonnet 50 in 1958. A total of 31 backcrossed seeds produced plants. The seeds from each plant were sent to the hoja blanca testing laboratory, then located at Camaguey, Cuba, and backcross populations carrying hoja blanca resistance were identified. Space-planted populations of each backcross line also were grown in the breeding nursery at Beaumont in 1959, and plants were selected from the lines that were promising for hoja blanca resistance. In 1960, F_3 lines were tested for hoja blanca reaction in Colombia, and for straighthead reaction at Eagle Lake. F_2 lines were also sown at Campo Cotaxtla, near Veracruz, Mexico, in the fall of 1959; and two crops per year were obtained through 1961. Selections from the Mexico nursery were sent to Colombia for testing for hoja blanca reaction and to Beaumont for grain quality testing. By the end of 1961, many long-grain selections promising for hoja blanca resistance were available for extensive testing at Beaumont. Long-grain selections of early and midseason maturity that are resistant to hoja blanca and straighthead and that possess Bluebonnet milling, processing, and cooking qualities were tested for yield and other field characters at Beaumont in 1963.

Since hoja blanca resistance is dominant, Bluebonnet 50 was used as the recurrent parent in the modified backcross method. The hoja blanca reaction of F_1 backcross plants was obtained at the hoja blanca testing laboratory at Baton Rouge, La. In 1963, F_1 plants with four backcrosses to Bluebonnet 50 were tested for hoja blanca reaction. Some of these plants are similar to Bluebonnet 50 in plant and grain type and they are resistant to hoja blanca.

Description of Varieties

The names and accession numbers of the 18 varieties reported in this section of the handbook are listed in table 9. These include the principal commercial varieties in the United States.

Short-Grain Varieties

In 1963, about 12.3 percent of the total rice acreage in the United States was sown with short-grain (Pearl) varieties.⁵ In Arkansas, Louisiana, Mississippi, and Texas only 0.08 percent of the crop produced was the short-grain type, whereas in California, 67.7 percent was this type.

The commercial short-grain varieties grown in yield tests were Caloro, Cody, and Colusa. Rough rice and milled kernels of each of these three varieties are shown in figure 21. These and other short-grain varieties have rather slender culms, narrow (about $\frac{3}{8}$ -inch) leaf blades, and yellow or straw-colored rough hulls enclosing the kernels. A plant of Caloro is shown in figure 22. When milled, short-grain varieties usually yield as high a percentage of head rice (whole grain milled) as do the medium-grain varieties and higher than do the long-grain varieties. Short-grain varieties are not grown in the Southern States because the varieties available are not well adapted for this area and there is little demand in this area for rice of this type.

CALORO.—Caloro was selected from Early Wataribune in 1913 at the Biggs Rice Field Station, Biggs, Calif., and was distributed in the

spring of 1921. It is an early to midseason, partly awned variety that heads and matures uniformly in California and produces relatively high yields with reasonably good milling quality on either virgin soil or old ricelands. It is the leading variety grown in California, yields well in Arkansas (50, 51, 67) and Missouri (63), and yields reasonably well in Louisiana and Texas. Although it appears to be adapted for growing under a wide range of conditions, it is grown principally in California. Caloro is the most important short-grain variety grown in the United States.

CODY.—Cody (57) was selected from the cross Colusa \times Lady Wright at the Biggs Rice Field Station, Biggs, Calif. Seed of Cody was tested in Missouri and then increased and distributed to growers in Arkansas in the spring of 1944. Cody is an early-maturing, awnless variety that can be grown in all rice-producing States. It yields and mills well in the absence of diseases. It has been grown on a small acreage in Arkansas but has not been grown in California.

COLUSA.—Colusa (25) was selected in 1911 at the Rice Experiment Station, Crowley, La., from Chinese, a variety introduced from Italy in 1909 by Haven Metcalf. It was tested at the Biggs Rice Field Station, Biggs, Calif., and distributed in 1917 and 1918. Colusa is an early-maturing, awnless variety of reasonably good milling quality that heads and matures rather uniformly and that produces relatively high yields on fertile land. In California it is much less productive than Caloro on old riceland of average fertility. However, when nitrogen fertilizer is applied at

⁵ See footnote 2, p. 19.



FIGURE 21.—Rough rice and milled kernels of (A) Caloro, (B) Cody, and (C) Colusa.

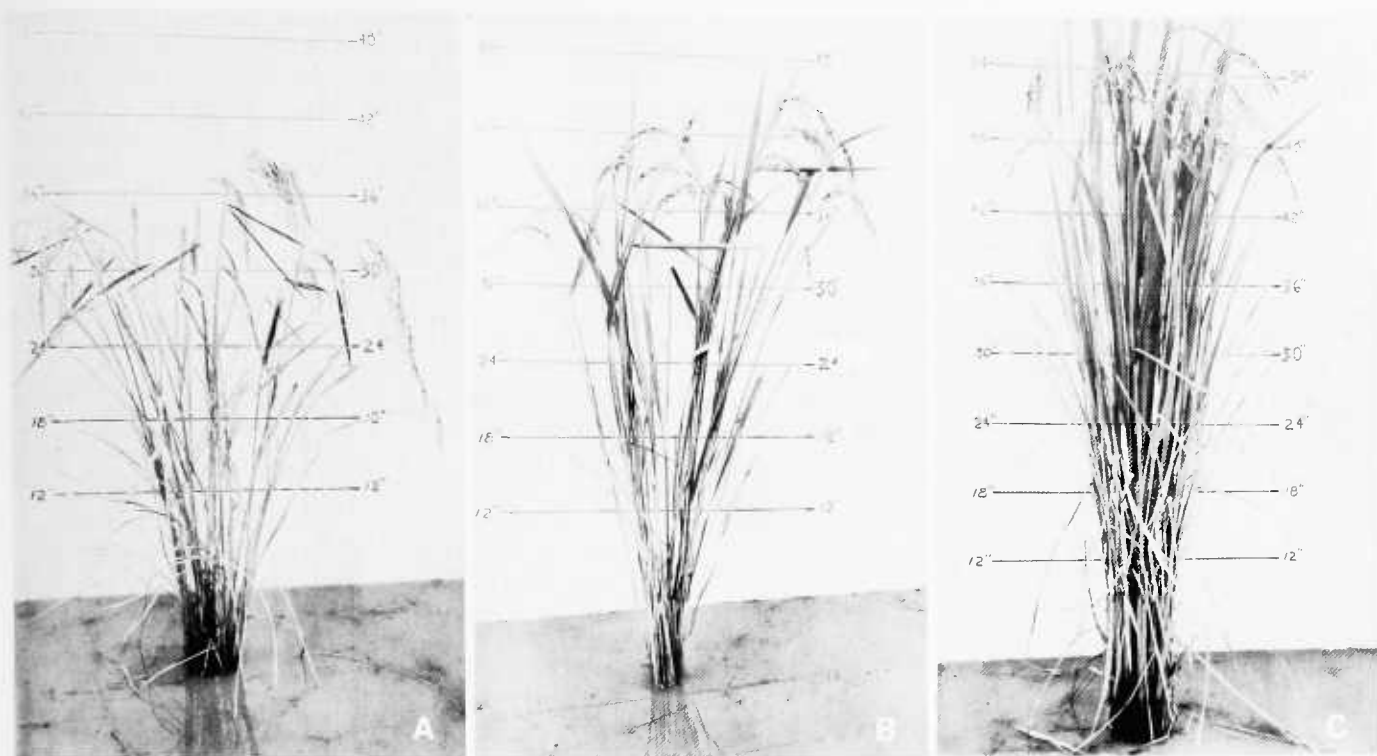


FIGURE 22.—Plants of (A) Caloro, (B) Nato, and (C) Rexoro.

TABLE 9.—Name, C.I. number, FAO number, and registration number for reported rice varieties

Grain type and variety	C.I. number ¹	FAO number ²	Registration number ³	Uniform group ⁴
Short-grain:				
Caloro -----	1561-1	211	5	IV
Cody -----	8642	212	20	I
Colusa -----	1600	213	8	I
Medium-grain:				
Arkrose -----	8310	207	1	IV
Calrose -----	8988	1013	6	IV
Gulfrose -----	9416	1339		I
Magnolia -----	8318	216	12	I
Nato -----	8998	1133	13	I
Northrose -----	9407	1364		I
Zenith -----	7787	206	19	I
Long-grain:				
Belle Patna -----	9433	1334		VI
Bluebonnet 50 -----	8990	1012	3	III
Century Patna 231 -----	8993	1014	7	II
Rexoro -----	1779	214	14	V
Sunbonnet -----	8989	1019	15	III
Texas Patna -----	8321	221	16	V
Toro -----	9013	1134	18	III
TP 49 -----	8991	1020	17	V

¹ Accession number, Cereal Crops Research Branch, Crops Research Division, Agricultural Research Service.

² Accession number, World Catalogue of Genetic Stocks—Rice. Food and Agriculture Organization of the United Nations.

³ Registration number, American Society of Agronomy—U.S. Department of Agriculture (48).

⁴ Uniform Yield Nursery Group number.

fairly high rates, it produces as much as Caloro. Colusa yields well in Missouri and fairly well on fertile land in Arkansas, but it frequently lodges

when the crop is heavy. Colusa has been for many years, and still is the most popular early-maturing variety grown in California.

Medium-Grain Varieties

In 1963, 47.5 percent of the rice acreage in the United States was sown to medium-grain varieties.⁶ In California, 32.3 percent of the rice acreage was sown to this type. Of the total rice production in the United States, Nato made up 38.6 percent, Zenith 0.1 percent, and the Roses (principally Arkrose, Calrose, Gulfrose, and Northrose) 8.7 percent.

The principal medium-grain varieties grown in the yield tests were Arkrose, Calrose, Gulfrose, Magnolia, Nato, Northrose, and Zenith. Rough rice and milled kernels of each of these seven varieties are shown in figure 23. These varieties, with the exception of Calrose, have rather stout culms and relatively wide (about $\frac{5}{8}$ -inch) leaf blades. A plant of Nato is shown in figure 22. When milled, medium-grain varieties usually yield more head rice (whole kernels) than the long-grain varieties yield.

ARKROSE.—Arkrose (57) was selected at the Rice Branch Experiment Station, Stuttgart, Ark.,

⁶ See footnote 2, p. 19.

from the cross Caloro \times Blue Rose. Arkrose was distributed in 1942. Arkrose matures about a week earlier than Supreme Blue Rose, and in some sections of Arkansas it is meeting the demand for a Blue Rose type. Arkrose yields well and is relatively easy to thresh. It is similar to Blue Rose in milling and table quality. It is more difficult to dry artificially than are most long-grain varieties. Arkrose has been grown in Arkansas and, rarely, in Texas.

CALROSE.—Calrose (57) was selected at the Biggs Rice Field Station, Biggs, Calif., from the cross Caloro \times Calady backcrossed to Caloro. It is a partly awned variety very similar in growth habit and maturity to Caloro. In California, Calrose appears to be equal to Caloro in yielding capacity and in milling quality. It stands up well, matures evenly, and is as easy to combine as Caloro. Calrose was grown on a small acreage for the first time in 1948, and in 1963 it was grown on 32.3 percent of the California rice acreage.

GULFROSE.—Gulfrose was selected from the cross Bruinmissie selection \times Zenith at the Rice-

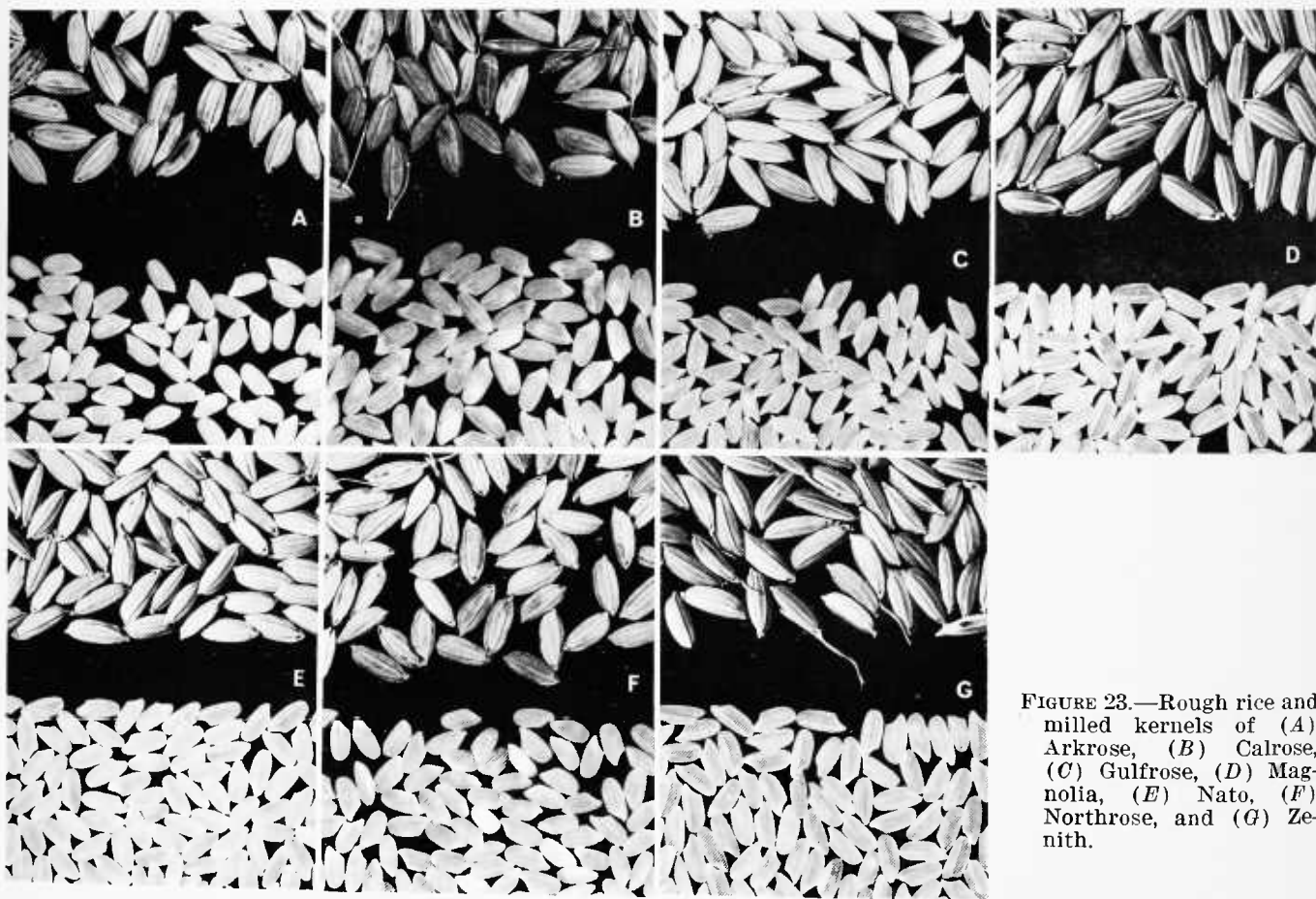


FIGURE 23.—Rough rice and milled kernels of (A) Arkrose, (B) Calrose, (C) Gulfrose, (D) Magnolia, (E) Nato, (F) Northrose, and (G) Zenith.

Pasture Research and Extension Center, Beaumont, Tex., in 1953, and released in 1960 (1). It is similar to Zenith in plant and grain type but matures a few days earlier. Gulfrose is resistant to hoja blanca. This was the principal reason for releasing it since none of the leading United States varieties grown at that time were resistant. Gulfrose was grown on a limited acreage in the southern rice area in 1963.

MAGNOLIA.—Magnolia (57) was selected at the Rice Experiment Station, Crowley, La., from the cross Improved Blue Rose \times Fortuna. It was released in 1945. It is an early-maturing variety that matures about the same time as Zenith. Magnolia usually heads and matures evenly and it combines more readily than Zenith. Under favorable conditions it produces relatively high yields, with good milling quality. The grain can be dried satisfactorily. Magnolia appears to be adapted for growing throughout the southern rice area.

NATO.—Nato was selected from the cross (Rexoro \times Purple-leaf) \times Magnolia at the Rice Experiment Station, Crowley, La. It was released in 1956. It is an early-maturing variety with comparatively short, strong straw; it produces good field and mill yields; and it is suitable for making dry cereals and for other uses for which varieties of similar type are adapted (43). Nato was the leading rice variety in the United States in 1963.

NORTHROSE.—Northrose was selected in 1955 from the cross Lacrosse \times Arkrose and released from the Rice Branch Experiment Station, Stuttgart, Ark., in 1962. It is an early-maturing variety, and its outstanding characters are its short, stiff straw and high grain yields. Because of its tendency to be slightly chalkier than Nato and because of its occasional low yields of head rice, Northrose was not designated for general production. Instead it was designated a special-purpose variety for relatively late seeding in northeast Arkansas where its earliness and high degree of lodging resistance are urgently needed (52, 53).

ZENITH.—Zenith (57) was selected from Blue Rose in 1930 by Glen K. Alter, near DeWitt, Ark. In 1931, several selections were tested in the cooperative breeding program at the Rice Branch Experiment Station, Stuttgart, Ark. Of these selections, Arkansas 141-8 proved to be the best; it was named Zenith and distributed in 1936. Zenith is an early-maturing, awnless variety, and it is uniform in heading and in maturing. In 1954, Zenith was grown on over 50 percent of the rice acreage in the Southern States. It has since been replaced by the shorter strawed, smooth-hulled Nato variety. Strains similar to Zenith have been isolated from Early Prolific.

Long-Grain Varieties

In 1963, 49.1 percent of the rice produced in Arkansas, Louisiana, Mississippi, and Texas was the long-grain type.⁷ The leading long-grain varieties were Bluebonnet 50 and Sunbonnet, comprising 33.5 percent of the southern acreage; Belle Patna, 10.6 percent; Rexoro, 2.9 percent; and Century Patna 231 and Toro, each 1.1 percent.

The principal long-grain varieties grown in the field tests were Belle Patna, Bluebonnet 50, Century Patna 231, Rexoro, Sunbonnet, Texas Patna, Toro, and TP 49. Rough rice and milled kernels of each of these eight varieties are shown in figure 24. Most of these varieties have rather large culms and relatively wide (about $\frac{5}{8}$ -inch) leaf blades. A Rexoro plant is shown in figure 22. Because of the long growing season required, Rexoro, Texas Patna, and TP 49 are grown only in Louisiana and Texas.

BELLE PATNA.—Belle Patna was selected from the cross Rexoro \times (Hill selection \times Bluebonnet) at the Rice-Pasture Research and Extension Center and was released in 1961 (2). It is a very early-maturing, slender-grain variety with cooking quality similar to Rexoro.

BLUEBONNET 50.—Bluebonnet 50 was selected from Bluebonnet in 1950 at the Rice-Pasture Research and Extension Center. Bluebonnet was a progeny of the cross Rexoro \times Fortuna. Seed of Bluebonnet 50 was distributed in 1951. Bluebonnet 50 is a midseason variety. It has relatively short, stiff straw, and the grains are partly awned. It yields and mills well and has good cooking quality, being comparable to Rexoro and Texas Patna in those characters. The grain of Bluebonnet 50 is thicker than that of Rexoro but is more slender than that of Nira. Bluebonnet 50 is well suited for harvesting by the combine-drier method.

CENTURY PATNA 231.—Century Patna 231 (57) was selected in 1946 from a cross between Texas Patna and a selection from the cross Rexoro \times Supreme Blue Rose at the Rice-Pasture Research and Extension Center. It was released to farmers in the spring of 1951. It is an early-maturing, slender-grain variety. Century Patna 231 usually matures about 3 days later than Zenith. It has rather short straw and narrow, semidrooping leaves, and tillers exceptionally well. Century Patna 231 is moderately resistant to the common races of the fungus causing the narrow brown leaf spot disease, so the leaves and stems remain alive for some time following maturity. In cooking quality, Century Patna 231 is inferior to Bluebonnet 50, Rexoro, and Texas Patna.

⁷ See footnote 2, p. 19.

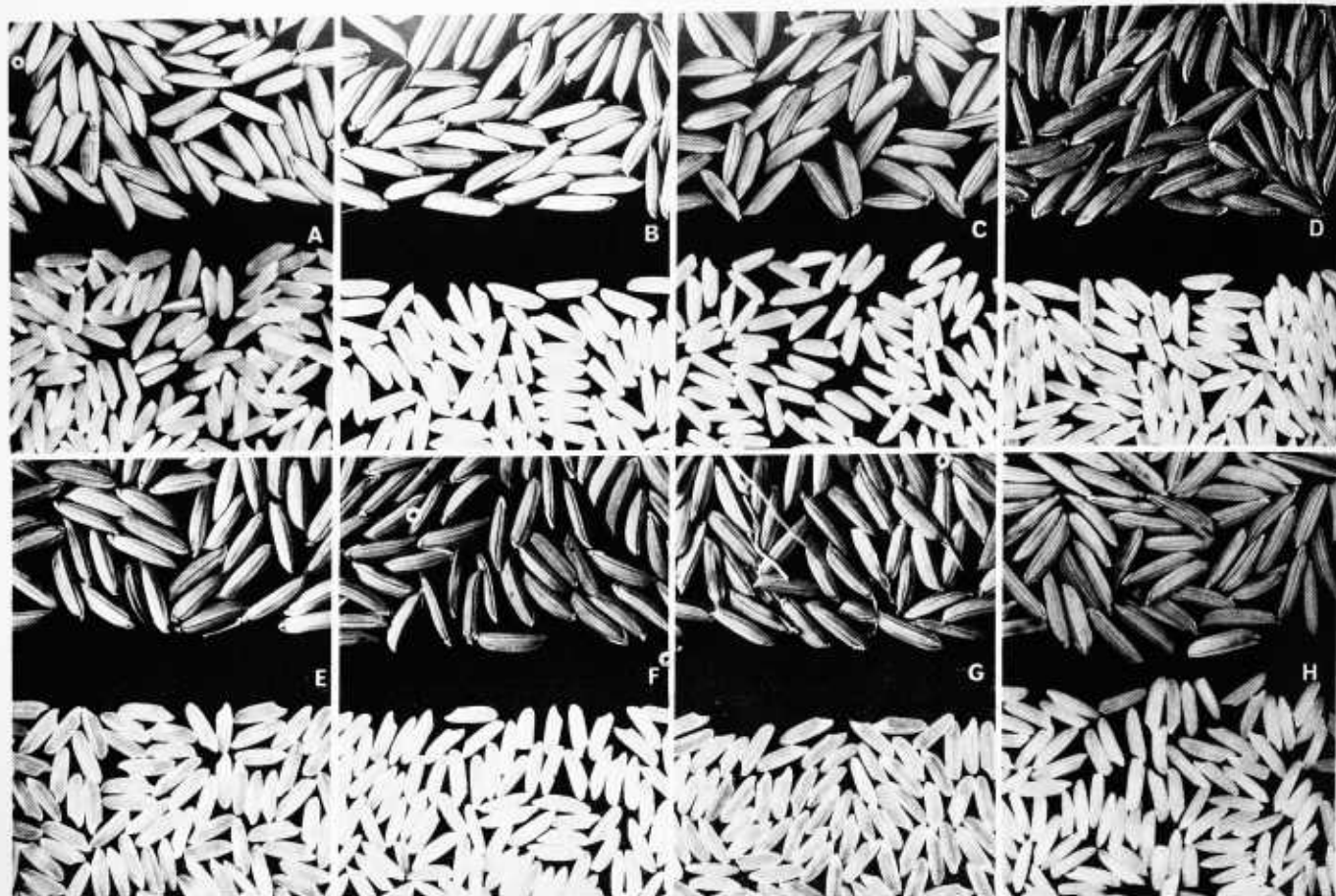


FIGURE 24.—rough rice and milled kernels of (A) Belle Patna, (B) Bluebonnet 50, (C) Century Patna 231, (D) Rexoro, (E) Sunbonnet, (F) Texas Patna, (G) Toro, and (H) TP 49.

REXORO.—Rexoro (25) was selected in 1926 at the Rice Experiment Station, Crowley, La., from the Marong-Paroc variety introduced from the Philippine Islands in 1911 by the U.S. Department of Agriculture. Rexoro was distributed by the Department in cooperation with the Louisiana Agricultural Experiment Station in 1928. Rexoro is a stiff-strawed, late-maturing, slender-grain rice that yields and mills well for a variety of this type. The cooking quality is very good.

SUNBONNET.—Sunbonnet was selected from Bluebonnet at the Rice Experiment Station, Crowley, La., and released in 1953 (42). Sunbonnet is similar to Bluebonnet in plant characters, although somewhat taller than Bluebonnet 50. Sunbonnet is similar to Bluebonnet in cooking quality but is usually slightly superior in milling quality.

TEXAS PATNA.—Texas Patna (57) was selected in 1935 at the Rice-Pasture Research and Extension Center from the cross Rexoro \times C.I. 5094. Seed of Texas Patna was distributed to growers in 1942. Texas Patna is similar to Rex-

oro but grows slightly taller, matures about 10 days earlier, and has a more translucent grain. It yields and mills well. Because Texas Patna is slightly taller than Rexoro, it is more inclined to lodge when grown on rich land. It is well suited for combining and the grain is easy to dry. Texas Patna is grown principally in the Eagle Lake section of Texas and to a limited extent in Louisiana.

TORO.—Toro was selected from a cross in which the varieties Bluebonnet, Blue Rose, and Rexoro were the parents. It was developed at the Rice Experiment Station, Crowley, La., and released in 1955 (42). It is similar to Bluebonnet 50 in plant height and straw strength. It yields and mills well, but it is about as hard to thresh as Zenith. The grain type is similar to that of Bluebonnet, but the cooking quality of these two varieties is different. Toro, when cooked, is firmer than Bluebonnet but not as dry and flaky.

TP 49.—TP 49 (48) was selected from the cross Texas Patna \times (Rexoro \times C.I. 7689) at the Rice-Pasture Research and Extension Center

and released in 1951. It is a late-maturing, slender-grain variety, similar to Texas Patna except that it has shorter and stronger straw and somewhat thicker grain.

Other Kinds of Rice

Most of the rice varieties grown in the United States are generally called common varieties; that is, they have no distinctive flavor or odor when cooked, and the starch in the endosperm contains both amylose and amylopectin. There are, however, minor acreages of two other kinds of rice—aromatic or scented, and glutinous or waxy.

AROMATIC OR SCENTED.—Varieties having a distinctive odor and flavor somewhat like popcorn when cooked are known as aromatic or scented varieties; they are cultivated widely in India and other southeast Asian countries. Scented rices are said to be low yielding; but because they are greatly esteemed, they may sell at twice the price of other rices of fine quality. The odor and flavor are assumed to be due to an aromatic substance. Since aroma is sometimes noted in the growing crop, it is not limited to the endosperm. The aroma occurs in waxy as well as in ordinary types of rice.

Two varieties, Delitus and Salvo, were selected from introductions released in the United States. Delitus has been grown commercially, and attempts have been made to place it on the market. A cross between Rexoro and Delitus produced Delrex and R-D, which fully retain the flavor. R-D is a productive, medium-late variety that should make possible profitable marketing of scented rice as a food specialty. C.I. 9483, an early-maturing selection from R-D \times Rexoro-Zenith, has improved milling quality and a more translucent endosperm.

GLUTINOUS OR WAXY.—Waxy varieties, commonly called glutinous, differ from common varieties in that they contain only amylopectin starch in the endosperm. Glutinous rice is grown on about 1,000 acres in California each year. It is grown as a specialty crop, and the acreage needed to meet market demands has been small. Historically, the principal use of glutinous rice has been for preparing oriental ceremonial foods and confections. In some countries, glutinous rice is harvested slightly green, is lightly parched before milling, and is used as a breakfast food. Recent research has shown that glutinous rice flour may find a special use in the frozen food industry. The flour, when made into foods for freezing, such as white sauce and desserts, resists syneresis (separation or weeping) when thawed after freezing.

Mochi Gomi is the variety of this type grown in California. It is a short-grain, midseason variety. Compared to Caloro, it has about the same straw strength and is about 6 inches shorter.

The glumes are less pubescent, and the grain matures 5 to 10 days later. The waxy-white kernels are opaque.

Performance of Varieties

The performance of rice varieties is studied at several rice experiment stations in the southern rice area and in California. The grain yields and milling quality data reported for the southern rice area in this bulletin were obtained from the Uniform Yield Nurseries from 1951 through 1961. In these nurseries, varieties are grown in 3- or 4-row, randomized, quadruplicated, drill-seeded plots. These nurseries were grown each year in Arkansas, Louisiana, and Texas, and in some years in Florida and Mississippi. Yields reported for California were obtained from drill-seeded, quadruplicated nursery plots except in 1960 and 1961, when the rice was seeded in the water.

Entries in the Uniform Yield Nurseries grown in the southern rice area are grouped according to grain type and length of growing season. The six groups are: I, short- and medium-grain early varieties; II, long-grain early varieties; III, long-grain midseason varieties; IV, short- and medium-grain midseason varieties; V, long-grain late varieties; and VI, medium- and long-grain very early varieties. There usually were 14 entries in each group, many of them experimental varieties. Group numbers of the 18 varieties reported in this section of the handbook are in table 9, p. 43.

The varietal experiments at each location were on soil that was typical of large areas in the respective States. In Florida the tests were made on Everglades peaty muck soil. Crop rotation, seedbed preparation, time and rate of seeding, fertilization, and weed control used for these experiments were practices that were thought to be optimum for each area.

Average grain yields in table 10 were obtained from 1951 through 1961 at the following locations: Rice Branch Experiment Station, Stuttgart, Ark.; Everglades Experiment Station, Belle Glade, Fla.; Rice Experiment Station, Crowley, La.; Delta Branch Experiment Station, Stoneville, Miss.; Rice-Pasture Research and Extension Center, Beaumont, Tex.; and Rice Experiment Station, Biggs, Calif. The actual number of years each variety was tested is shown. The yield of each variety is compared with the yield of one or two standard varieties that were grown throughout the entire period.

In Arkansas, the short-grain varieties all produced the highest average yields except those of the medium-grain varieties Arkrose and Northrose. All medium-grain varieties except Magnolia produced higher average yields than did

TABLE 10.—*Grain yield for 18 rice varieties grown at 6 locations during the 11-year period, 1951-61*

Grain type and variety	Arkansas			Florida			Louisiana			Mississippi			Texas			California		
	Years grown	Yield ¹		Years grown	Yield ¹		Years grown	Yield ¹		Years grown	Yield ¹		Years grown	Yield ¹		Years grown	Yield ²	
		Number	Pounds		Percent	Number		Pounds	Percent		Number	Pounds		Percent	Number		Pounds	Percent
Short-grain :																		
Caloro -----	11	4201	109	5	2023	61	10	2852	91	6	5836	129	9	3314	94	11	3375	100
Cody -----	10	4149	111	5	2559	78	10	3423	113	5	4034	89	10	3642	100			
Colusa -----	11	4242	110	5	2862	87	11	2743	88	6	4036	90	11	3754	103	11	3555	105
Medium-grain :																		
Arkrose -----	11	4338	112	5	3344	101	10	3080	98	6	6064	134	9	3575	101			
Calrose -----	11	4174	108	5	2073	63	10	2721	87	6	5514	122	9	3134	89	11	3544	105
Gulfrose -----	4	4715	107				4	2804	80	3	4715	103	4	3559	90			
Magnolia -----	11	4008	104	5	2806	85	11	3114	100	6	4273	95	11	3454	95			
Nato -----	10	4510	109	5	3640	110	10	3250	107	6	4477	99	10	3786	103			
Northrose -----	4	4933	112				4	3802	109	3	5337	117	4	4158	105			
Zenith -----	11	4156	108	5	3232	98	11	3231	104	6	4227	94	11	3593	98			
Long-grain :																		
Belle Patna ---	4	3834	87				4	3245	93	3	4543	99	4	3476	87			
Bluebonnet 50	11	3556	92	5	3365	102	11	3012	96	6	4791	106	11	3703	102			
Century Patna																		
231 -----	11	4128	107	5	3350	102	11	3674	118	6	5083	113	11	3540	97			
Rexoro -----							11	2128	68				11	2676	73			
Sunbonnet ---	11	3592	93	5	3758	114	11	2922	94	6	4863	108	11	3827	105			
Texas Patna ---							11	2404	77				11	3009	82			
Toro -----	10	4113	100	5	3594	109	10	3237	106	6	4869	108	10	3738	102			
TP 49 -----							11	2417	77				11	3269	90			

¹ Percent of the yield is based on the mean of Zenith and Bluebonnet 50 for the years grown; quantity \therefore given in pounds per acre.² Percent of yield is based on the yield of Caloro.

most of the long-grain varieties. Century Patna 231 produced nearly the same average yield as the medium-grain varieties, but the other long-grain varieties produced lower average yields.

In Florida, none of the short-grain varieties produced an average yield that was as high as that of the higher yielding medium- or long-grain varieties. Of the medium-grain varieties, Nato produced the highest average yield. The long-grain variety Sunbonnet produced the highest average yield of any variety.

In Louisiana, Cody was the only short-grain variety that produced an average grain yield comparable to the yields of the higher yielding medium- and long-grain varieties. The highest yielding medium-grain varieties were Nato and Zenith, except for Northrose, which was grown only 4 years. Of the long-grain varieties, Century Patna 231 and Toro produced high average yields. The late-maturing, long-grain varieties Rexoro, Texas Patna, and TP 49 produced quite low yields.

In Mississippi, Caloro produced the highest average yield of the short-grain varieties tested, but the other two short-grain varieties produced quite low yields. Arkrose, Calrose, and Northrose produced highest average yields of the medium-grain varieties tested. The average yield of these three varieties was somewhat higher than that of the long-grain varieties. Of the long-grain varieties, Century Patna 231 produced the highest yield. All long-grain varieties except Belle Patna produced higher average yields than did many of the commonly grown medium-grain varieties.

In Texas, the short-grain varieties Cody and Colusa produced average yields comparable to the higher yielding medium- and long-grain varieties. Of the medium-grain varieties, Nato and Arkrose produced highest average yields except for Northrose, which was grown only 4 years. Sunbonnet, Bluebonnet 50, and Toro produced highest average yields of the long-grain varieties.

In California, Colusa and Calrose produced slightly higher average yields than did Caloro.

The average number of days from seeding to maturity, average plant height, estimated straw strength, and pubescence and color of hull for the 18 varieties included in this handbook are given in table 11.

Milling quality was determined each year for the varieties grown in the Uniform Yield Nurseries. Included in table 7, p. 36, are the average milling yields of hulls, bran, total, and head rice for each of 18 varieties grown in the Uniform Yield Nurseries in Arkansas, Louisiana, and Texas for the years 1958-61. Milling yields were determined according to the modified procedure of Beachell and Halick (19). Treatment and preparation of Uniform Yield Nursery samples

before milling was described in the section "Testing for Milling, Cooking, and Processing Qualities," p. 33. The average milling yields of hulls ranged from 18 percent for the short-grain varieties Caloro and Colusa to 21 percent for the long-grain variety Century Patna 231. Average bran yields ranged from 9 percent to 13 percent. In general, bran yields were lower for short- and medium-grain varieties than for long-grain varieties. Northrose, a newly released, special-purpose, medium-grain variety yielding an average of 12 percent bran, was an exception. The late-maturing, long-grain varieties Rexoro and Texas Patna grown only in Louisiana and Texas produced the highest bran yields (13 percent) of any of the varieties tested.

The average yield of total milled rice varied from 67 percent for Century Patna 231 to 73 percent for Caloro and Colusa. Short-grain varieties, as a group, produced slightly higher yields of total milled rice than did medium- and long-grain varieties. The medium-grain variety Northrose and the long-grain varieties Century Patna 231, Rexoro, and Texas Patna gave the lowest total milled rice yields.

Head rice yields for the varieties listed in table 7 are reported as average values and as individual minimum and maximum (range) values. Average yields of head rice varied widely among the varieties, from 52 percent for Rexoro to 69 percent for Calrose. In general, the average yield of head rice was highest for the short- and medium-grain varieties and lowest for the long-grain varieties. Toro, a long-grain variety yielding 67 percent of head rice, was an exception. The milling quality of this variety has been noted in earlier publications (19, 41). Individual minimum and maximum values of head rice yields also varied widely. This variability was evident, not only among varieties but also within the varieties. Individual minimum head rice yields ranged from 33 percent for Arkrose to 63 percent for Calrose, Magnolia, and Nato; whereas individual maximum values ranged from 61 percent for Rexoro to 75 percent for Colusa.

Choosing the Variety

Several factors affect the choice of a variety. These are listed by Johnston, Cralley, and Henry (51) as market demand, satisfactory yielding ability, location, proposed seeding date, soil fertility or anticipated fertilizer practices, relative maturity, susceptibility to diseases that may occur, and seed supply. Growers of large acreages may wish to sow two or three varieties that differ in date of maturity and grain type in order to extend the harvesting period and to provide rice of different types for the market.

A grower should carefully consider market re-

TABLE 11.—*Plant characters for 18 rice varieties grown at 6 locations during the 11-year period, 1951-61*¹

Grain type and variety	Average time from seeding to maturity ²						Average plant height						Estimated straw strength ³	Hull pubescence ⁴	Hull color
	Arkan- sas	Flor- ida	Loui- siana	Missis- sippi	Texas	Cali- fornia	Arkan- sas	Flor- ida	Loui- siana	Missis- sippi	Texas	Cali- fornia			
	<i>Days</i>	<i>Days</i>	<i>Days</i>	<i>Days</i>	<i>Days</i>	<i>Days</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>			
Short-grain:															
Caloro -----	141	149	145	133	138	153	46	31	44	39	46	35	Weak-----	R	Straw.
Cody -----	129	127	122	⁵ 124	119	-----	44	36	42	39	46	-----	Midstrong-	R	Straw.
Colusa -----	130	128	123	124	118	134	46	37	43	36	47	34	Very weak.	R	Straw.
Medium-grain:															
Arkrose -----	150	153	150	144	142	-----	52	44	50	47	52	-----	Very weak.	R	Straw.
Calrose -----	141	148	143	129	137	153	46	32	43	37	46	33	Weak-----	R	Straw.
Gulfrose -----	126	-----	121	123	116	-----	48	-----	43	37	47	-----	Weak-----	S	Straw.
Magnolia -----	134	127	127	131	121	-----	51	45	46	42	50	-----	Weak-----	R	Straw.
Nato -----	132	127	126	130	122	-----	47	41	42	41	47	-----	Midstrong-	S	Straw.
Northrose -----	134	-----	130	128	123	-----	46	-----	42	37	43	-----	Strong-----	S	Straw.
Zenith -----	133	129	126	134	122	-----	50	44	46	44	50	-----	Midstrong-	R	Straw.
Long-grain:															
Belle Patna -----	115	-----	108	118	109	-----	43	-----	42	36	45	-----	Weak-----	S	Straw.
Bluebonnet 50 -----	149	145	140	147	137	-----	47	44	45	49	50	-----	Strong-----	S	Straw.
Century Patna 231 -----	136	133	131	137	126	-----	47	37	43	44	48	-----	Strong-----	S	Gold.
Rexoro -----	-----	-----	174	-----	172	-----	-----	-----	50	-----	52	-----	Strong-----	S	Gold.
Sunbonnet -----	148	143	140	147	137	-----	52	47	48	51	54	-----	Strong-----	S	Straw.
Texas Patna -----	-----	-----	166	-----	149	-----	-----	-----	50	-----	55	-----	Very weak.	S	Gold.
Toro -----	148	144	140	148	137	-----	49	44	45	48	49	-----	Strong-----	S	Straw.
TP 49 -----	-----	-----	172	-----	165	-----	-----	-----	48	-----	52	-----	Weak-----	S	Gold.

¹ Years of test: Arkansas, 1951-61; Florida, 1953-56; Louisiana, 1951-61; Mississippi, 1959-61; Texas, 1951-61; and California, 1951-61.² Average seeding date: Arkansas, May 7; Florida, March 31; Louisiana, April 17; Mississippi, May 18; Texas, April 24; and California, May 6.³ Based on results for Arkansas and Texas.⁴ R = pubescent; S = glabrous.⁵ 2-year average.

quirements in selecting varieties to grow. He or his marketing agent may have difficulty in selling his rice if it is of poor quality, even though locally the variety may produce high yields. Also, growing a short- or medium-grain variety on a limited basis in an established long-grain district, for example, can pose real problems to the grower, driers, warehousemen, and millers to prevent mixtures of the different types.

Seeding rice on highly fertile soil, such as newly cleared woodland, "new ground," or a field used as a reservoir just before being seeded to rice, would necessitate the choice of a stiff-strawed variety that would be less likely to lodge. Even on old riceland low in natural fertility, if a grower anticipates using heavy rates of nitrogen fertilization, with part of it applied relatively late, such a practice may make it desirable to choose a relatively early-maturing variety. Growers in the northern part of ricegrowing areas in the United States are limited to early-maturing varieties because of the somewhat shorter growing season and cooler night temperatures than those prevailing farther south. It may be desirable to avoid a given variety because of its susceptibility to a certain disease when rice is to be grown under conditions known to be favorable for development of that disease.

Varietal Response to Seeding Date

By NELSON E. JODON

Results of Tests With Older Varieties

Growers need to know how rice varieties will respond when sown at various dates. They should be able to tell the probable effect on yield, days to full maturity, plant height, milling quality, and other characters. Date-of-seeding tests have been conducted at Arkansas, Louisiana, Texas, and California rice experiment stations.

At Stuttgart, Ark., an experiment was carried on for 5 years with 10 varieties seeded at three dates (5). The average seeding dates were April 20, May 11, and June 5. Bluebonnet and Blue Rose yielded well from the first two seedings but usually matured too late when seeded in June. Arkrose yielded about the same from each of the seeding dates. The highest average yields from the latest seeding were made by Cody and Zenith, which have shorter growing seasons.

Most varieties sown in June in Arkansas risk injury by possible October frosts, although Arkrose and Zenith seeded in mid-June and Caloro and Cody seeded late in June have produced satisfactory yields (51). Nato should be seeded before the first of June and Bluebonnet by May 25. In the northern part of the State, seeding should be 7 to 10 days earlier.

In an Arkansas experiment, Arkrose and Blue

Rose matured in shorter periods of time when sown late than did Bluebonnet (3). Varieties that responded to the shortened days of late summer by heading at nearly the same date whether seeded early or late were termed photosensitive. They also headed out quickly and uniformly. Length of time required for the photosensitive varieties to reach the heading stage decreased with each delay in the seeding date; plant height also decreased. Varieties that did not continue to shorten their growing period in response to late seeding were termed indifferent.

In Louisiana, the maximum number of days to flowering resulted from seedings on March 1 or March 15, except for the variety Caloro (37), in an experiment reported in 1936. The minimum for all varieties was from June 15 seedings. The difference between maximum and minimum days to flowering was a varietal characteristic. Some varieties tended to have a comparatively fixed growing period; others tended to head at a certain date late in the season, and if sown late, their growing periods were shortened materially. The maximum number of days from first heading to full maturity was 45; this number added to the number of days to flowering for each variety gave the total length of the growing period.

Another field plot experiment with six varieties was conducted over a 5-year period in Louisiana and reported in 1944 (38). The seeding dates were approximately the 15th and the 1st of each month from March 15 to June 15. Best yields were obtained from April 1 and May 1 seedings. Lower yields were obtained from June seedings than from April and May seedings.

The rice varieties Bluebonnet, Magnolia, Rexoro, and Zenith were grown in a date-of-seeding test in Louisiana and reported in 1953. In all, 27 seedings were made on dates as early as February 20 and as late as June 20 in the years 1941 to 1952 (40). Usually, four seedings were made each season. A tabular guide (40) for use in planning seeding schedules gave, for alternate days during the planting period, the growing season midpoint date (latest date to topdress), date of first heading, date when mature for combining, and total length of the growing period.

Nine varieties were seeded monthly from mid-March to mid-July in a 3-year experiment conducted at Beaumont, Tex., (72) and reported in 1954. Yields of early varieties showed no definite relation to seeding date, but midseason varieties gave markedly lower yields from May and later seedings. Late varieties gave the best yields from the earliest seedings and failed to mature from June and July seedings.

Effects of 10-hour daylight periods on length of growing period were studied in Texas (17). The day length was reduced by covering the

plants part of each day. Similar results were obtained from the 10-, 20-, and 30-day periods of short-day treatment. Two groups of varieties, termed sensitive and less sensitive, were compared. Varieties in the sensitive group showed a marked reduction in the number of days from seeding to heading when the treatments began about 50 days after seeding. The less sensitive varieties in general responded only slightly from the 50-day treatment but responded more when the treatments were started 60 to 80 days after seeding. The response depended on the variety. Reduction in length of growing period was accompanied by reduction in number of tillers and panicles, plant height, and straw and grain weight.

At Biggs, Calif., a date-of-seeding test was conducted for 9 years (54). Three seedings of the Wataribune variety were made each year, beginning as early as possible in the spring. The seedings were made at 2-week intervals. In all but 1 year's test, the highest yields were obtained from the earliest seeding.

Results of Tests With Newer Varieties and Selections

Tests similar to those reported in 1953 (40) were continued in Louisiana in the 9 years from 1953 through 1961 (44, pp. 8-25). In these experiments, seedings were made each year in March, April, May, and June. Each year the seedings were made to coincide with peaks of planting operations on farms in the area. Entries included varieties from four maturity groups. These included Nato (early), Sunbonnet and Toro (midseason), Blue Rose and R-D (medium late), and Rexoro (late). They mature in about 120, 135, 150, and 165 days, respectively. Extra early types (100-day group) were first included in 1957. One or two standard varieties representative of each maturity group were tested throughout the 9-year period. Each year additional entries of current interest were included.

Data for individual varieties are used in the following discussion of length of life cycle. Data for yield, height, and milling quality were averages of a standard variety and two other varieties or selections belonging to each of the four maturity groups, except in the late group. In the late group, data for only Rexoro and one selection were used for 2 of the years. The early group included Nato and two other varieties; the midseason group, Sunbonnet, Toro, and one other variety; the medium-late group, Blue Rose, R-D, and one other variety; and the late group, Rexoro and one other variety. Thus, the three varieties included in maturity-group averages for each month of the seeding period were the same in any 1 year; but, aside from the standard variety,

they were not necessarily the same from year to year.

LENGTH OF LIFE CYCLE IN RELATION TO SEEDING DATE.—Average number of days from seeding to first heading by monthly seeding date for six varieties representing four maturity groups are summarized in table 12. Date of first heading was used as the criterion of the length of growing season of varieties, since it can be determined more precisely than date of maturity. The length of the period from first heading to maturity ranged from 35 to 40 days for the varieties listed. During warm weather, however, varieties that head very evenly may ripen in 30 days after the tips of panicles first emerge from the boot; whereas late in the growing season, the period from panicle emergence to full maturity may be 45 to 50 days.

Relative heading dates of five of the six varieties were fairly constant when sown at successively later dates, although the number of days from seeding to heading was progressively fewer. Nato headed 14 to 18 days earlier than Sunbonnet or Toro. Sunbonnet and Toro headed 12 to 19 days earlier than R-D. Rexoro was 9 to 17 days later than R-D. The number of days from seeding to heading for Blue Rose decreased more than some varieties as seeding was delayed. Blue Rose headed 1 day later than R-D when sown in March; but when sown in June, it headed 19 days earlier than R-D and 7 days earlier than Sunbonnet.

The reduction of length of life cycle of Blue Rose from successive seedings is an example of photoperiodic response. This response is governed by the length of the dark period during the 24-hour day. Blue Rose may be termed phototensitive and the other varieties may be said to have relatively inflexible growing seasons because their life cycles tend to remain constant in length once a certain minimum has been reached. For example, Nato seeded in June reached maturity in only 4 days less time than when it was seeded in May.

Low temperatures in the early spring retard germination and seedling development, thus extending the length of the life cycle. Average lengths of life cycles from April seedings were 17 days less than from March seedings. Those from May seedings were only 8 days less than from April seedings, and those from June seedings were only 9 days less than from May seedings.

The greater reduction in number of days from seeding to maturity in April as compared with March seeding was caused by greater temperature differences that occur between April and later seeding dates. The further reduction obtained from May and June seedings probably was largely the result of photoperiodic response. Be-

TABLE 12.—Average days from seeding to first heading of 6 rice varieties representing 4 maturity groups, when sown in each of the 4 months of the planting period in the years from 1953 to 1961

Maturity group and variety	Time of seeding				Average
	March	April	May	June	
Early:	<i>Days</i>	<i>Days</i>	<i>Days</i>	<i>Days</i>	<i>Days</i>
Nato.....	103	88	80	76	87
Midseason:					
Sunbonnet.....	118	103	98	93	103
Toro.....	118	102	96	90	102
Medium-late:					
Blue Rose.....	137	115	102	86	110
R-D.....	136	121	115	105	119
Late:					
Rexoro.....	153	137	127	114	133
Average.....	128	111	103	94	-----

cause of slow ripening late in the growing season. very late seedings tend to lengthen the life cycle rather than reduce it.

Seven varieties that mature in from 100 to 165 days were sown at four successive dates each year from 1953 to 1961. The response of these varieties is shown in figure 25. The upper part of the

curve for each variety, representing the earlier part of the planting period, tended to be steep, because when the weather warmed in the spring, the length of the period from seeding to heading was rapidly reduced. Further reduction in time until heading for five of the seven varieties proceeded at a slower but comparatively uniform

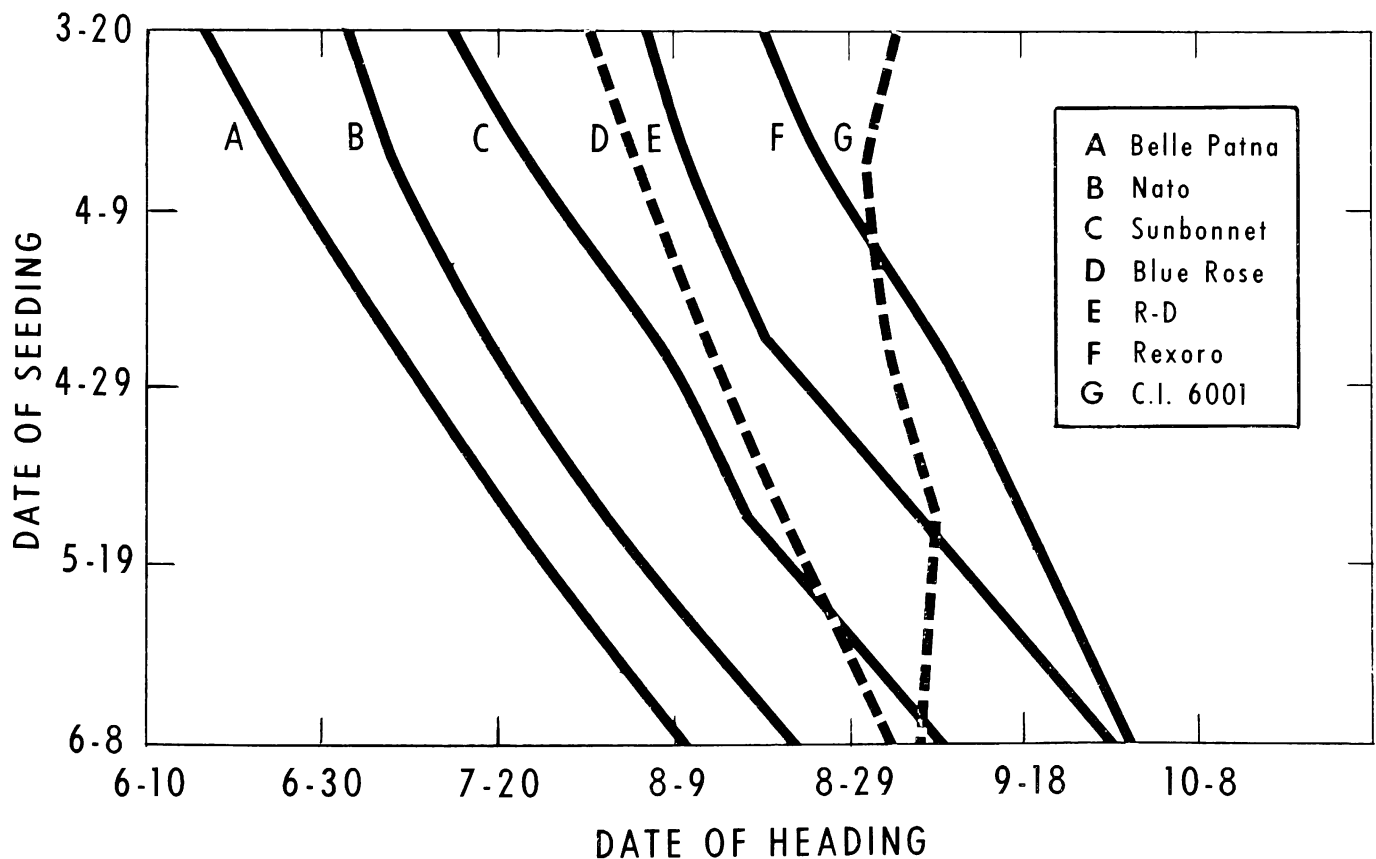


FIGURE 25.—Heading date in relation to seeding date of 7 adapted varieties grown at Crowley, La., from 1953 to 1961.

rate through the remainder of the season. Consequently, the curves indicating the response of those five varieties are roughly parallel.

Blue Rose and C.I. 6001 had steeper curves than did the other five varieties. This reflected greater sensitivity to photoperiod. C.I. 6001 was later than R-D and Rexoro when seeded early but became earlier from subsequent seeding. Blue Rose was later than Sunbonnet when seeded early but became earlier from subsequent seeding.

Early-maturing varieties do not show the characteristics of photoperiodic response, otherwise they would not head during the long days of June and July. Or possibly the critical length of the dark period is much shorter for them than for the more sensitive later varieties.

All varieties have a vegetative stage of development during which they are not photosensitive. The less sensitive midseason and later varieties may have a longer vegetative stage than do the early varieties.

Sensitive and short-season (early) varieties may be seeded later than less sensitive midseason or late varieties. However, Arkrose and Caloro are the only sensitive varieties now in production. Any of the less sensitive varieties can be used for successive seedings because the plants mature in the order seeded, and the fields can be harvested without conflict.

Data obtained from date-of-seeding experiments may be used to predict time of maturity of rice varieties. This information makes it possible to schedule seedings so that different fields and varieties may be harvested consecutively. The approximate dates of maturity of eight varieties when sown at 10-day intervals, March 1 to June 30, in southwest Louisiana are shown in table 13.

YIELDS IN RELATION TO SEEDING DATE.—Aver-

age yields of variety groups by monthly seeding dates are summarized in table 14. Production of the early varieties varied but little because of date of seeding. Midseason and medium-late varieties were less productive from June seedings than from earlier seedings. Yields from May seedings of Rexoro and other late varieties were reduced. Yields from June seedings were unprofitably low or were complete failures.

Probably Rexoro should not be seeded after about May 20 at the latest (40), and April seeding is preferred. Currently, no medium-late varieties, such as Blue Rose, are in production. These have been replaced by early-maturing, medium-grain varieties. The midseason varieties Bluebonnet 50 and Sunbonnet may be seeded in Louisiana as late as the first week of June with satisfactory results. Nato and other early varieties may be seeded in Louisiana at any time from early March to the end of June with expectation of profitable yields. In some years blast may be serious during the warm humid weather in the summer months. During years when this disease is prevalent, there may be a reduction in stand of late-sown susceptible varieties. There may at the same time be a reduced yield from early-sown, short-season varieties caused by the rotten-neck phase of blast.

PLANT HEIGHT IN RELATION TO SEEDING DATE.—Average plant heights of four groups of varieties by monthly seeding ranges are summarized in table 15. Midseason and late varieties were taller than were early varieties. Midseason varieties seeded in June and late varieties seeded in May and June were shorter than when seeded earlier. Adair (3) reported that in Arkansas later seedings produced shorter straw, and Beachell (17) found a marked reduction in plant

TABLE 13.—*Approximate dates of maturity of 8 rice varieties when sown at 10-day intervals in southwest Louisiana*

Seeding date	Belle Patna	Gulfrose	Nato	Bluebonnet, Sunbonnet, or Toro	Texas Patna	Rexoro
Mar. 1-----	7-13	7-25	7-28	8-13	9-8	9-18
10-----	7-17	7-27	7-30	8-15	9-11	9-20
20-----	7-22	8-2	8-4	8-22	9-15	9-25
30-----	7-26	8-4	8-9	8-27	9-21	10-2
Apr. 10-----	8-2	8-13	8-16	8-31	9-27	10-6
20-----	8-9	8-21	8-22	9-5	10-3	10-13
30-----	8-14	8-27	8-30	9-15	10-7	10-19
May 10-----	8-21	8-31	9-5	9-21	10-13	10-25
20-----	8-29	9-4	9-15	10-1	10-18	10-30
30-----	9-5	9-12	9-24	10-11	10-25	11-4
June 10-----	9-13	9-23	9-30	10-18	11-3	11-15
20-----	9-26	10-4	10-9	10-25	11-12	(1)
30-----	10-8	10-16	10-17	11-4	(1)	(1)

¹ Failed to mature.

TABLE 14.—Average yields of 3 rice varieties in each of 4 maturity groups, from seedings made in each of the 4 months of the planting period in the years from 1953 to 1961

Time of seeding	Maturity groups				Average
	Early	Midseason	Medium-late	Late	
	<i>Pounds per acre</i>	<i>Pounds per acre</i>	<i>Pounds per acre</i>	<i>Pounds per acre</i>	<i>Pounds per acre</i>
March-----	2,771	2,740	2,634	2,521	2,667
April-----	2,674	2,744	2,852	2,324	2,649
May-----	2,604	2,632	2,826	2,172	2,568
June-----	2,623	2,395	2,452	¹ 1,197	² 2,167
Average-----	2,668	2,628	2,691	³ 2,054	-----

¹ Late varieties failed in 1954 and 1957.

² Average of June seedings, late group excluded, 2,490.

³ Average of late varieties, June seeding excluded, 2,339.

TABLE 15.—Average plant heights of 3 rice varieties in each of 4 maturity groups, from seedings made in each of the 4 months of the planting period in the years from 1953 to 1961

Time of seeding	Maturity groups				Average
	Early	Midseason	Medium-late	Late	
	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>
March-----	43	47	49	49	47
April-----	44	47	50	49	48
May-----	44	47	49	48	47
June-----	45	46	45	45	45
Average-----	44	47	48	48	-----

height of varieties that headed in response to a 10-hour photoperiod.

The reductions in average heights from later seedings, as shown in table 15, correspond to reduced yields in the respective months, as shown in table 14.

A correlation of 0.25 between height and yield within individual varieties from seedings in the earlier months indicates that higher yields tend to be associated with greater plant heights from early, medium, or late seeding dates. This does not mean that short-strawed varieties necessarily tend to be low yielding. However, among fields of the same variety, plants with taller straw are likely to be higher yielding than those with shorter straw. Exceptions to this generalization may occur when nitrogen fertilizer is applied at different times.

MILLING QUALITY IN RELATION TO SEEDING DATE.—Average percentages of head rice from varieties representative of four groups are summarized according to monthly seeding date in table 16. No comparison can be made of the average milling quality of these groups because

of the lack of correspondence in grain type of the varieties within groups.

March seeding resulted in low percentages of head rice, probably because of higher temperatures during the maturation period. Ripening is hastened in hot weather, and more chalky grains are produced. Also, rapid changes in temperature and moisture tend to cause checking of the grain. Compared to March seedings, April and May seedings gave improved milling quality. The average percentage of head rice was 3 percent higher from May than from April seedings.

The average percentages of head rice from May and June seedings were equal. However, the midseason and especially the late varieties were lower in milling quality from June seedings, probably because of effects of low temperatures late in the season.

The early and medium-late, medium-grain varieties tended to give increasingly higher percentages of head rice from each successive seeding. Thus, apparently improved milling quality is a major advantage of late seeding.

TABLE 16.—Average percentages of head rice from samples of 3 rice varieties in each of 4 maturity groups, from seedlings made in each of the 4 months of the planting period in the years from 1953 to 1961

Time of seeding	Maturity groups				Average
	Early	Midseason	Medium-late	Late	
	Percent	Percent	Percent	Percent	Percent
March.....	57	53	49	47	52
April.....	60	56	54	49	55
May.....	60	61	57	52	58
June.....	65	59	58	48	58

Production of Seed Rice

By T. H. JOHNSTON

Origin of High-Quality Seed Rice

According to Wise (88), new and superior varieties of crops make their intended contributions to agriculture only "when the seed stocks of such crops reach the farmer varietally pure, in a viable condition, free of noxious weeds, in adequate quantities and at a reasonable price."

To produce this high-quality seed, a grower must have a source of superior seed of a well-adapted variety. Promising new strains are compared to standard varieties continually at the rice experiment stations to determine their adaptation. When an experimental strain proves to be superior to standard varieties, it is increased for release to growers.

Formerly each farmer could obtain a small amount of seed of a new or standard variety and thereafter produce his own seed. However, modern harvesting and processing methods, including bulk drying and storage, have increased the possibility of mixing. These methods and the use of more specific types of varieties that differ in maturity, grain type, and processing and cooking quality have emphasized the need for sources of pure seed. As a result, the seed certification program now in effect in each major rice-producing State is an important part of the rice industry.

"Minimum Seed Certification Standards" (36) states:

The purpose of Seed Certification is to maintain and make available to the public sources of high quality seeds and propagating materials of superior varieties so grown and distributed as to insure genetic identity. Only those varieties that contain superior germ plasm are eligible for certification. Certified seed is high in varietal purity and of good seedling value.

Varieties eligible for certification have resulted either from natural selection or through systematic plant breeding. In either case without a planned method of maintaining genetic purity, there is grave danger of losing varietal identity.

Varietal purity is the first consideration in seed cer-

tification but other factors, such as weeds, diseases, viability, mechanical purity and grading are also important. One of the most effective methods of preventing the wider distribution of weeds is to plant weed-free seed. Adverse effects of plant diseases can be reduced by planting clean seed from disease-free fields. Properly cleaned and graded seed is easier to plant and gives more uniform stands.

Seed certification is designed, therefore, to maintain not only the genetic purity of superior crop varieties, but also reasonable standards of seed condition and quality.

It also is stated in this publication:

Only those varieties that are approved by a State or Governmental agricultural experiment station and accepted by the certifying agency shall be eligible for certification.

In general, before a variety is approved by an experiment station, it must be tested thoroughly (usually for a minimum of 3 years), and it must show merit as a new variety in production, disease resistance, or some other outstanding character.

Classes of Seed in a Certification Program

The classes of seed usually included in a certification program are breeder, foundation, registered, and certified. These are described by the International Crop Improvement Association (36) as follows:

(1) *Breeder seed* is seed directly controlled by the originating, or, in certain cases, the sponsoring plant breeder or institution, and which provides the source for the initial and recurring increase of foundation seed.

(2) *Foundation seed* shall be seed stocks that are so handled as to most nearly maintain specific genetic identity and purity and that may be designated or distributed by an agricultural experiment station. Production must be carefully supervised or approved by representatives of an agricultural experiment station. Foundation seed shall be the source of all other certified seed classes, either directly or through registered seed. White tags are used to designate this class of seed.

(3) *Registered seed* shall be the progeny of

foundation or registered seed that is so handled as to maintain satisfactory genetic identity and purity and that has been approved and certified by the certifying agency. Purple tags are used to designate this class of seed.

(4) *Certified seed* shall be the progenies of foundation, registered; and, in some cases, previously certified blue tag seed that is so handled as to maintain satisfactory genetic identity and purity and that has been approved and certified by the certifying agency. Blue tags are used to designate this class of seed.

For the production of the various classes of certified seed, it is necessary to have clean land and to prevent mixtures in seeding, harvesting, and processing. Although careful roguing of all fields to remove undesirable weeds, other crops, or offtype plants increases the production costs, it is necessary.

The production of breeder and foundation seed is an integral part of the cooperative rice-breeding projects of the U.S. Department of Agriculture and the Agricultural Experiment Stations. The production and certification of registered and certified seed are not a part of the breeding program.

BREEDER SEED PRODUCTION.—After an experimental variety of rice has been developed in the coordinated breeding program and has been proved sufficiently outstanding, procedures are begun to purify it and to provide a seed supply for possible release to growers for commercial production.

Procedures differ at the various experiment stations but the steps included usually are somewhat as follows: (1) From 100 to 500 panicles are selected from the interior rows of nursery or field plots of the experimental variety; (2) these panicles are weighed and the weight is added to the plot weight so as not to cause inaccurate plot yield reports; (3) each panicle is inspected and any having offtype seeds is discarded; (4) each panicle typical of the variety is threshed individually; and (5) the seeds are placed in a small envelope.

The following year the seed from each panicle that passed the screening test is sown in a single row from 4 to 20 feet long and 12 to 24 inches apart. In some cases there are 3-foot alleys between ranges of rows to facilitate careful inspection and roguing. The block of panicle rows of each variety is isolated from those of varieties similar in maturity so as to eliminate natural crossing and subsequent segregation for offtypes.

After the seedlings emerge, they are carefully inspected at intervals to identify any offtype plants or rows. Rows that show offtype plants or any apparent differences at any stage are removed immediately or tagged for removal before harvest. In the early seedling stage, special em-

phasis is given to noting albino seedlings or variable plant types. Later in the season special attention is paid to uniformity of vegetative growth and heading within and among rows. During the ripening period, careful observations are made to detect differences in plant type, plant height, panicle type, pubescence, color of apex or apiculus, and grain type. If the entire group of panicle rows appears uniform, the rows are harvested in bulk.

However, if considerable variability attributed to genetic segregation is evident or if numerous offtype plants are found, then it may be necessary to make further selection of rows for purification. This may be done by selecting from within a block of rows individual rows that appear to be uniform in appearance and that typify the variety being increased.

The grain from 30 to 50 or more such rows (families) may be harvested separately after 25 to 100 panicles are selected from each row. A number is assigned to each family for maintaining its identity. The following year, from 10 to 20 or more rows may be sown from the bulk seed of each family, or a similar number of panicle rows from panicles saved from each family row may be used instead of the bulk.

An alternate method would be to select a few panicles from all rows that appear to be typical of the variety and grow three to six panicle rows of each row.

The panicles saved from each family row are examined individually for offtypes and are grown by seeding each family in a group or block of 3 to 25 or more panicle rows. As before, the rows are observed for offtype or undesirable type plants in the seedling and later stages. If several offtypes are found within a family or if the rows within a family tend to be variable or are not typical of the variety, the entire family may be eliminated. If there still appears to be too much variation in the material, it may be necessary to again select individual rows from families most similar in plant type. Several rows may be selected from each of several families, again identifying the families and subfamilies, and the subfamilies grown in panicle-row blocks the following year. Usually at this stage the material is sufficiently uniform, so that there are only a few offtypes to discard or eliminate.

If a variety needs to be released as soon as possible because of a disease emergency, for example, one procedure would be to increase and release seed at an earlier stage and at a designation lower than foundation seed. Purification of the variety could be continued and foundation seed could be released as soon as it becomes available.

It may be desirable to check the processing and cooking quality of the bulk seed from each

family row used in the purification increase. Useful quality tests are the alkali digestion (65) and iodine-blue tests (34). The final bulk representing all the family lines should be grown in variety trials to determine the overall performance of the mass-selected strain.

One method used to produce breeder seed of established varieties is to select panicles from the best available source of seed of that variety, such

as a field being grown for production of foundation seed. Depending on the facilities available and the amount of seed desired, individual panicles may be selected in quantities varying from 500 to possibly 5,000. These panicles are carefully inspected and those that are typical for the variety are threshed individually and head rows are grown (fig. 26).

One procedure that has helped to eliminate



FIGURE 26.—Breeder seed head-row block.

natural crosses with other varieties has been to seed the block of breeder panicle rows within the area of a foundation field of the same variety. Each row must be examined carefully throughout the growing season and atypical rows eliminated. Failure to eliminate a row with a few offtype plants will adulterate the seed produced, and it must be discarded. Typical rows are bulked. The family method described for selecting new varieties may be necessary if a commercial variety becomes badly mixed. But this

method should be used as a last resort, since severe mass selection may result in genetic alteration of the original variety.

An alternate method used for the production of breeder seed of established varieties is to start with the best source available and, depending on the amount of breeder seed desired, to carefully handpick a given quantity of seed to eliminate grains that appear to be offtype or to have other undesirable characteristics. This handpicked seed can be drilled thinly, possibly at one-fourth

the normal rate, in rows 50 to 150 feet long, spaced 12 or more inches apart. This increase block then is observed very carefully at intervals throughout the growing season, and off-type plants are eliminated. This method is much less time consuming than the panicle-row method and appears to be quite satisfactory for well-established varieties that have been purified several times previously. This method may be preferred to the panicle-row method, since there is less chance of genetic alteration.

A system that was inaugurated at Beaumont, Tex., in 1962 may eliminate growing breeder seed panicle rows of a variety after a pure source of breeder seed is established. Under this system the plant breeder produces a fairly large quantity of seed from panicle rows or family blocks that is true to type for the variety. This seed is cleaned and put into 50- to 100-pound containers and is placed in storage under conditions suitable for maintaining the viability for at least 10 years. One or more units from storage can be sown each succeeding year to produce foundation seed.

The advantage of this method is that once a variety is purified, a continuing source of seed of known purity is available. To carry this system one additional step, a portion of the seed used to produce the seed for storage is saved and stored under conditions suitable for retaining the viability for more than 25 years. Each 5 to 10 years, or as needed, a portion of this remnant seed may be sown to produce another supply of breeder seed identical to that originally stored.

FOUNDATION SEED PRODUCTION.—Foundation seed usually is the first year increase from breeder seed. Foundation seed is produced on fields that have not grown another variety or a lower class of the same variety during the 2 previous years. Preventing mixtures throughout the various phases of seed production requires very close attention when several varieties are handled with the same equipment. To facilitate roguing of foundation seed fields, a space is left every few feet by stopping up one or more of the holes in the farm-type grain drill used for seeding. Such fields should be rogued several times during the last part of the growing season. Insofar as possible, foundation seed fields are managed to produce satisfactory grain yields without excessive vegetative growth and to minimize lodging. It is impossible to satisfactorily rogue a field in which an appreciable amount of lodging has occurred.

The release of foundation seed to growers usually is handled through a committee or seed council or similar organization that allots the seed to carefully selected growers, often on the basis of rice acreage within a county or parish. Sometimes the seed is turned over to a seed grow-

ers' organization or crop improvement association. Sometimes foundation seed is distributed directly to growers from the State agricultural experiment station. For new varieties or for old varieties in short supply, requested amounts of seed may be reduced in proportion to the amount that is requested.

Cleaning, Grading, and Processing Seed Rice

Cleaning and processing seed rice is an exacting operation that requires specialized equipment. Where conditions and facilities permit, it is desirable to delay harvesting seed rice until the moisture content is below 20 percent. If the combine harvester is carefully adjusted, the rough rice coming from "clean" fields may be relatively free of stems, weed seeds, and trash so that it can be unloaded and safely elevated directly into aerated bins without prior aspirating or scalping. In such case the seed rice is placed in hopper-bottom bins and aerated with an excess of air to dry the grain or at least keep it from heating. Where necessary, the air may be heated to facilitate drying of the seed rice to a moisture level sufficiently low for safe storage. If rice coming from the field contains considerable foreign material, it may be advisable to partly clean it with a scalper-aspirator machine before putting it in the bin for aeration. In some locations, facilities and conditions require that the rough rice be dried before it can be safely stored. This drying may require that the rice be passed through the drier several times. Frequently the rice is aspirated between passes to remove foreign matter and light-weight, immature grains. Extreme care must be exercised to prevent mechanical mixing if the drying and cleaning facilities are used for more than one variety of rice.

The first step in the cleaning and grading process is to put the rice through a fanning mill, which has the following parts: (1) a wind aspirator that removes light grain, hulls, and other light-weight foreign material; (2) a screen with large perforations that removes any remaining sticks, stems, mud lumps, or large weed seeds; and (3) a finely perforated screen that removes the finer broken rice grains, small weed seeds, and other small particles of foreign material. It may be necessary to put the rice through the cleaner a second time to remove less easily separated material such as shelled rice grains and weed seeds or an excess of light-weight, underdeveloped grains.

The next step is a grain-length separation that may be accomplished either by a disk or an indented cylinder-type machine. Small pockets or indents in revolving disks or cylinders retain the shorter length grains (including broken grains and hulled grains) slightly longer while the grain is lifted by the revolving disk or cylinder. A

special compartment collects and eliminates the rejected material from the grain.

The third step in the cleaning and grading process is a diameter or width separation that removes any large diameter rice grains, weed seeds, or foreign materials. For this operation either a vertical screen or a perforated cylinder grader is used. The grains of normal diameter pass through the screen perforations while the grains of larger diameter, the weed seeds, or foreign materials are retained and thus removed from the sample. For successful length and width separations, the sample should be free from sticks, stems, and other foreign materials because such materials will interfere with the proper functioning of the machine.

The length and diameter grading of seed rice has been extremely useful in removing the larger diameter red rice grains from seed of long-grain varieties. The use of these graders has been important in the control of red rice. In medium- and short-grain varieties, the only means of red rice control is the use of red rice free seed and land, since no economical method of separation has as yet been devised. In some instances long-grain red rice types have occurred in the long-grain varieties. Whenever a lot of long-grain seed rice has a mixture of long-grain red rice, it should be discarded immediately and not used

for seed. The propagation of seed containing long-grain red rice will soon result in a wide infestation of the soil with long-grain red rice strains and will further complicate the maintenance of pure seed production.

Following the diameter-grading operation, the seed rice usually is treated with a fungicide and often with an insecticide and placed in well-marked 100-pound bags. The seed is then ready for distribution to selected growers.

Each of the rice experiment stations has a plant for processing seed rice. These plants are designed to make the installations as nearly self-cleaning as possible. They are being constantly improved as new and improved equipment and methods are developed. Gravity movement of bulk seed is used whenever possible. Steel or metal-lined bins with smooth walls and gravity flow metal hopper bottoms simplify cleaning the facilities. Belt conveyors are preferred to other types because of ease of cleaning.

The seed rice processing plant at Stuttgart, Ark., was described by Williams (86). It includes a concrete dump pit, a truck hoist, a 60-hundredweight-per-hour drier, two bucket-type elevators, ten 450-hundredweight bins, two half-size working bins, cleaning equipment, a seed treater, and 3,500 square feet of sack storage space (fig. 27). In addition, seven 35-hundred-



FIGURE 27.—Rice seed processing plant at Stuttgart, Ark.

weight bins are available for small lots of breeder seed. All bins are of steel construction and are equipped with aeration.

Small portable cleaning units without elevators or conveyors frequently are used for cleaning small lots of breeder seed. These small lots usually are dried on sack driers or small laboratory driers to further reduce hazards of mixing. Various sizes and types of seed-cleaning and handling equipment are described in detail by Hammond, Klein, and Brandenburg (35).

Standards for Seed Certification

The standards for field inspection and laboratory analysis of seed samples for seed certification are summarized in tables 17 and 18. These reflect the ranges in the standards for the seed certification agencies in the Southern States of Arkansas (Arkansas State Plant Board), Louisiana (Louisiana Department of Agriculture and Immigration), Mississippi (The Mississippi Seed Improvement Association), and Texas (The State Seed and Plant Board, Texas Department of Agriculture), and in California (California Crop Improvement Association).

In some States lots of seed that contain seed-transmissible diseases will not be certified, and in

other States lots of seed of this type must be reported.

In order for the rice to be eligible for certification, the seed rice field must not have had another rice variety or the same variety of lower class growing on it the previous 2 years. The field also must be isolated from other ricefields. When the seed rice field is drill seeded, the minimum isolation distances range from 10 to 29 feet with a ditch, fence, roadway, or other definite boundary. When the field is sown broadcast with ground equipment, the minimum isolation distance is 50 feet. When the adjoining field is seeded by airplane parallel to the seed rice field, the minimum isolation distance is 100 feet. When adjoining fields are seeded by airplane at right angles to the seed rice field, the minimum isolation distance is one-fourth mile. In California, all ricefields that are to produce certified seed must be marked before April 15 at the corners and at one-fourth-mile intervals by red or other vivid colored flags that are 3 feet square.

Specific requirements and standards are established for each State and a list of these is available from each of the official certifying agencies. In general, they are concerned with application procedures, field and harvest inspection, post-harvest seed movement, seed processing, and official sampling.

TABLE 17.—*Ranges among major ricegrowing States in standards for field inspection of rice for 1962*

Factor	Standards for each class		
	Foundation	Registered	Certified
	<i>Per acre</i>	<i>Per acre</i>	<i>Per acre</i>
Other varieties - definite	0	0 to 160 plants	10 to 200 plants.
Other varieties - similar grain type	0	Up to 160 heads	Up to 480 heads.
Curly indigo and other highly objectionable weeds	0	0	0.
Red rice	0	0 to 8 plants	0 to 18 plants.

TABLE 18.—*Ranges among major ricegrowing States in standards for cleaned seed of rice for 1962*

Factor	Standards for each class		
	Foundation	Registered	Certified
Pure seed (minimum)	98 to 99 percent	98 to 99 percent	98 to 99 percent.
Other varieties - definite (maximum)	0	0 to 1 per 5 pounds	3 per 5 pounds to 5 per pound.
Other varieties - doubtful (maximum)	0 to 7 per pound	0 to 10 per pound	0 to 20 per pound.
Other crop seed (maximum)	0 to 1 per pound	1 to 2 per pound	2 to 5 per pound.
Curly indigo, coffeebean, field bindweed	0	0	0.
Other noxious weeds (maximum)	0	0	1 in 2 pounds.
Red rice (maximum)	0	0 to 1 per 2 pounds	0 to 1 per pound.
Total weed seed (maximum)	0 to 0.05 per cent	0 to 0.1 percent	5 per pound to 0.1 percent.
Inert matter (maximum)	1 to 2 percent	1 to 2 percent	1 to 2 percent.
Germination (minimum)	80 to 85 percent	80 to 85 percent	80 to 85 percent.
Moisture (maximum)	14 percent	14 percent	14 percent.

Selected References

- (1) ANONYMOUS.
1960. GULFROSE . . . A NEW RICE VARIETY RESISTANT TO HOJA BLANCA DISEASE. Tex. Agr. Expt. Sta. Leaflet 484, 4 pp.
- (2) ———
1961. BELLE PATNA . . . A NEW SHORT-SEASON, LONG-GRAIN RICE VARIETY. Tex. Agr. Expt. Sta. Leaflet L-512, 4 pp.
- (3) ADAIR, C. R.
1940. EFFECT OF TIME OF SEEDING ON YIELD, MILLING QUALITY, AND OTHER CHARACTERS IN RICE. Amer. Soc. Agron. Jour. 32: 697-706.
- (4) ———
1941. INHERITANCE IN RICE OF REACTION TO HELMINTHOSPORIUM ORYZAE AND CERCOSPORA ORYZAE. U.S. Dept. Agr. Tech. Bul. 772, 19 pp.
- (5) ——— and CRALLEY, E. M.
1950. 1949 RICE YIELD AND DISEASE CONTROL TESTS. Ark. Agr. Expt. Sta. Rpt. Ser. 15, 20 pp.
- (6) ——— and JONES, J. W.
1946. EFFECT OF ENVIRONMENT ON THE CHARACTERISTICS OF PLANTS SURVIVING IN BULK HYBRID POPULATIONS OF RICE. Amer. Soc. Agron. Jour. 38: 708-716.
- (7) ——— MILLER, M. D., and BEACHELL, H. M.
1962. RICE IMPROVEMENT AND CULTURE IN THE UNITED STATES. Adv. in Agron. 14: 61-108.
- (8) ANDERSON, A. L., HENRY, B. W., and TULLIS, E. C.
1947. FACTORS AFFECTING INFECTIVITY, SPREAD, AND PERSISTENCE OF PIRICULARIA ORYZAE CAV. Phytopathology 37: 94-110.
- (9) ATEN, A., and FAUNCE, A. D.
1953. EQUIPMENT FOR THE PROCESSING OF RICE. FAO Devlpmt. Paper 27, 55 pp.
- (10) ATKINS, J. G., and ADAIR, C. R.
1957. RECENT DISCOVERY OF HOJA BLANCA, A NEW RICE DISEASE IN FLORIDA, AND VARIETAL RESISTANCE TESTS IN CUBA AND VENEZUELA. Plant Dis. Rptr. 41: 911-915.
- (11) ——— BEACHELL, H. M., and CRANE, L. E.
1956. REACTION OF RICE VARIETIES TO STRAIGHTHEAD. Tex. Agr. Expt. Sta. Prog. Rpt. 1865, 2 pp.
- (12) ——— BEACHELL, H. M., and CRANE, L. E.
1957. TESTING AND BREEDING AMERICAN RICE VARIETIES FOR RESISTANCE TO STRAIGHTHEAD. Internatl. Rice Comm. Newsletter 6(2): 12-15.
- (13) ——— BOLICH, C. N., JOHNSTON, T. H., and others.
1963. BREEDING FOR BLAST RESISTANCE IN THE UNITED STATES. Blast Symp. Proc., Internatl. Rice Res. Inst., Los Banos, Philippines. July.
- (14) ——— and JODON, N. E.
1963. ASPECTS OF BREEDING RICE FOR RESISTANCE TO DISEASES, PARTICULARLY BLAST (PIRICULARIA ORYZAE). Internatl. Rice Comm. Newsletter, Spec. issue, 10th Pacific Sci. Cong. Symp., pp. 41-52.
- (15) ——— and TODD, E. H.
1959. WHITE TIP DISEASE OF RICE. III. YIELD TESTS AND VARIETAL RESISTANCE. Phytopathology 49: 189-191.
- (16) AUTREY, H. S., GRIGORIEFF, W. W., ALTSCHUL, A. M., and HOGAN, J. T.
1955. RICE MILLING EFFECTS OF MILLING CONDITIONS ON BREAKAGE OF RICE GRAINS. Jour. Agr. and Food Chem. 3: 593-599.
- (17) BEACHELL, H. M.
1943. EFFECT OF PHOTOPERIOD ON RICE VARIETIES GROWN IN THE FIELD. Jour. Agr. Res. 66: 325-340.
- (18) ———
1959. RICE. In Matz, S. A., ed., The Chemistry and Technology of Cereals as Food and Feed, pp. 137-176. Avi Pub. Co., Inc., Westport, Conn.
- (19) ——— and HALICK, J. V.
1957. BREEDING FOR IMPROVED MILLING, PROCESSING AND COOKING CHARACTERISTICS OF RICE. Internatl. Rice Comm. Newsletter 6(2): 1-7.
- (20) ——— and HALICK, J. V.
1957. PROCESSING AND COOKING QUALITIES OF RICE AND METHODS FOR THEIR DETERMINATION. Presented Sixth meeting, Working Party on Rice Breeding, IRC, FAO, Vercelli, Italy, 9 pp.
- (21) ——— and JENNINGS, P. R.
1961. MODE OF INHERITANCE OF HOJA BLANCA RESISTANCE IN RICE. Rice Tech. Working Group Proc., pp. 11-12.
- (22) ——— JODON, N. E., JOHNSTON, T. H., and others.
1959. BREEDING RICE VARIETIES FOR RESISTANCE TO THE VIRUS DISEASE HOJA BLANCA. Internatl. Rice Comm. Newsletter 8(3): 6-9.
- (23) ——— SCOTT, J. E., EVATT, N. S., and others.
1961. BELLE PATNA. Rice Jour. 64(6): 6-8, 24-26.
- (24) BORASIO, L., and GARIBOLDI, F.
1957. ILLUSTRATED GLOSSARY OF RICE PROCESSING EQUIPMENT. FAO, Rome.
- (25) CHAMBLISS, C. E., and JENKINS, J. M.
1923. SOME NEW VARIETIES OF RICE. U.S. Dept. Agr. Dept. Bul. 1127, 17 pp.
- (26) CHILTON, S. J. P., and TULLIS, E. C.
1946. A NEW RACE OF CERCOSPORA ORYZAE IN RICE. Phytopathology 36: 950-952.
- (27) CRALLEY, E. M.
1949. WHITE TIP OF RICE. (Abstract) Phytopathology 39: 5.
- (28) CRANE, L. E.
1959. NEW RICE VARIETY, "GULFROSE," INTRODUCED. Rice Jour. 62(13): 2-3, 17.
- (29) DAVIS, L. L.
1950. CALIFORNIA RICE PRODUCTION. Calif. Agr. Ext. Ser. Cir. 163, 55 pp.
- (30) FRAPS, G. S.
1916. THE COMPOSITION OF RICE AND ITS BY-PRODUCTS. Tex. Agr. Expt. Sta. Bul. 191, 41 pp.
- (31) GEDDES, W. F.
1951. RICE. MILLING. In Jacobs, M. B., ed., The Chemistry and Technology of Food and Feed Products. 3 v. Interscience Pub., Inc., New York.
- (32) HALICK, J. V., BEACHELL, H. M., STANSEL, J. W., and KRAMER, H. H.
1960. A NOTE ON THE DETERMINATION OF GELATINIZATION TEMPERATURES OF RICE VARIETIES. Cereal Chem. 37: 670-672.
- (33) ——— and KELLY, V. J.
1959. GELATINIZATION AND PASTING CHARACTERISTICS OF RICE VARIETIES AS RELATED TO COOKING BEHAVIOR. Cereal Chem. 36: 91-97.
- (34) ——— and KENEASTER, K. K.
1956. THE USE OF A STARCH-IODINE-BLUE TEST AS A QUALITY INDICATOR OF WHITE MILLED RICE. Cereal Chem. 33: 315-319.
- (35) HARMOND, J. E., KLEIN, L. M., and BRANDENBURG, N. R.
1961. SEED CLEANING AND HANDLING. U.S. Dept. Agr., Agr. Handb. 179, 38 pp.

- (36) INTERNATIONAL CROP IMPROVEMENT ASSOCIATION.
1959. MINIMUM SEED CERTIFICATION STANDARDS. Pub. 19, 111 pp. Chambers Printing Co., Clemson, S.C.
- (37) JENKINS, J. M.
1936. EFFECT OF DATE OF SEEDING ON THE LENGTH OF THE GROWING PERIOD OF RICE. La. Agr. Expt. Sta. Bul. 277, 7 pp.
- (38) ——— and JONES, J. W.
1944. RESULTS OF EXPERIMENTS WITH RICE IN LOUISIANA. La. Agr. Expt. Sta. Bul. 384, 39 pp.
- (39) JODON, N. E.
1938. EXPERIMENTS ON ARTIFICIAL HYBRIDIZATION OF RICE. Amer. Soc. Agron. Jour. 30: 294-305.
- (40) ———
1953. GROWING PERIOD OF LEADING RICE VARIETIES WHEN SOWN ON DIFFERENT DATES. La. Agr. Expt. Sta. Bul. 476, 8 pp.
- (41) ———
1955. IMPROVING VARIETIES OF RICE AND SORGHUM. 47th Ann. Prog. Rpt., La. Rice Expt. Sta., pp. 83-87.
- (42) ———
1955. SUNBONNET AND TORO. 2 NEW MIDSEASON LONG-GRAIN RICE VARIETIES. La. Agr. Expt. Sta. Bul. 499, 12 pp.
- (43) ———
1957. NATO. AN EARLY MEDIUM-GRAIN RICE. La. Agr. Expt. Sta. Cir. 47, 14 pp.
- (44) ———
1961. PERFORMANCE OF RICE VARIETIES IN 1961. 53rd Ann. Prog. Rpt., La. Rice Expt. Sta., 162 pp. [Processed.]
- (45) ——— and CHILTON, S. J. P.
1946. SOME CHARACTERS INHERITED INDEPENDENTLY OF REACTION TO PHYSIOLOGIC RACES OF *CERCOSPORA ORYZAE* IN RICE. Amer. Soc. Agron. Jour. 38: 864-872.
- (46) ——— and DE LA HOUSSEY, D. A.
1949. RICE VARIETIES FOR LOUISIANA. La. Agr. Expt. Sta. Bul. 436, 15 pp.
- (47) ——— RYKER, T. C., and CHILTON, S. J. P.
1944. INHERITANCE OF REACTION TO PHYSIOLOGIC RACES OF *CERCOSPORA ORYZAE* IN RICE. Amer. Soc. Agron. Jour. 36: 497-507.
- (48) JOHNSTON, T. H.
1958. REGISTRATION OF RICE VARIETIES. Agron. Jour. 50: 694-700.
- (49) ——— ADAIR, C. R., TEMPLETON, G. E., and others.
1963. NOVA AND VEGOLD . . . NEW RICE VARIETIES. Ark. Agr. Expt. Sta. Bul. 675, 23 pp.
- (50) ——— and CRALLEY, E. M.
1955. RICE VARIETIES AND THEIR YIELDS IN ARKANSAS, 1948-1954. Ark. Agr. Expt. Sta. Rpt. Ser. 49, 20 pp.
- (51) ——— 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.
- (52) ——— TEMPLETON, G. E., WELLS, J. P., and HENRY, S. E.
1962. NORTHROSE, A NEW SPECIAL-PURPOSE RICE VARIETY FOR ARKANSAS. Rice Jour. 65(8): 10, 12-14, 18-19.
- (53) ——— TEMPLETON, G. E., WELLS, J. P., and HENRY, S. E.
1962. NORTHROSE RICE—A SPECIAL-PURPOSE, STIFF-STRAWED EARLY VARIETY FOR ARKANSAS. Ark. Farm Res. 11(2): 2.
- (54) JONES, J. W.
1923. RICE EXPERIMENTS AT THE BIGGS RICE FIELD STATION IN CALIFORNIA. U.S. Dept. Agr. Dept. Bul. 1155, 60 pp.
- (55) ———
1936. IMPROVEMENT IN RICE. U.S. Dept. Agr. Yearbook 1936: 415-454.
- (56) ———
1938. THE "ALKALI TEST" AS A QUALITY INDICATOR OF MILLED RICE. Amer. Soc. Agron. Jour. 30: 960-967.
- (57) ——— ADAIR, C. R., BEACHELL, H. M., and others.
1953. RICE VARIETIES AND THEIR YIELDS IN THE UNITED STATES 1939-50. U.S. Dept. Agr. Cir. 915, 29 pp.
- (58) ——— JENKINS, J. M., NELSON, M., and others.
1941. RICE VARIETIES AND THEIR COMPARATIVE YIELDS IN THE UNITED STATES. U.S. Dept. Agr. Cir. 612, 34 pp.
- (59) ——— JENKINS, J. M., WYCHE, R. H., and NELSON, M.
1938. RICE CULTURE IN THE SOUTHERN STATES. U.S. Dept. Agr. Farmers' Bul. 1808, 29 pp.
- (60) KARON, M. L., and ADAMS, MABELLE E.
1949. HYGROSCOPIC EQUILIBRIUM OF RICE AND RICE FRACTIONS. Cereal Chem. 26: 1-12.
- (61) KESTER, E. B.
1959. RICE PROCESSING. In Matz, S. A., ed., The Chemistry and Technology of Cereals as Food and Feed, pp. 427-461. Avi Pub. Co., Inc., Westport, Conn.
- (62) KIK, M. C., and WILLIAMS, R. R.
1945. THE NUTRITIONAL IMPROVEMENT OF WHITE RICE. Natl. Res. Council Bul. 112, 76 pp.
- (63) KING, B. M.
1937. THE UTILIZATION OF WABASH CLAY (GUMBO) SOILS IN CROP PRODUCTION. Mo. Agr. Expt. Sta. Res. Bul. 254, 42 pp.
- (64) LATTERELL, FRANCES M., TULLIS, E. C., and COLLIER, J. W.
1960. PHYSIOLOGICAL RACES OF *PIRICULARIA ORYZAE* CAV. Plant Dis. Rptr. 44: 679-683.
- (65) LITTLE, RUBY R., HILDER, GRACE B., and DAWSON, ELSIE H.
1958. DIFFERENTIAL EFFECT OF DILUTE ALKALI ON 25 VARIETIES OF MILLED WHITE RICE. Cereal Chem. 35: 111-126.
- (66) NAGAI, I.
1959. JAPONICA RICE. ITS BREEDING AND CULTURE. 843 pp. Yokendo Ltd., Tokyo.
- (67) NELSON, M., and ADAIR, C. R.
1940. RICE VARIETY EXPERIMENTS IN ARKANSAS. Ark. Agr. Expt. Sta. Bul. 403, 28 pp.
- (68) ORMROD, D. P., and BUNTER, W. A., JR.
1961. THE EVALUATION OF RICE VARIETIES FOR COLD WATER TOLERANCE. Agron. Jour. 53: 133-134.
- (69) POEHLMAN, J. M.
1959. BREEDING RICE. VARIETAL HISTORY OF RICE IN THE UNITED STATES. His Breeding Field Crops, pp. 174-189. Henry Holt and Co., Inc., New York.
- (70) RAMIAH, K.
1933. INHERITANCE OF FLOWERING DURATION IN RICE (*ORYZA SATIVA* L.). Indian Jour. Agr. Sci. 3: 377-410.
- (71) RAO, B. S., VASUDEVA MURTHY, A. R., and SUBRAHMANYA, R. S.
1952. THE AMYLOSE AND THE AMYLOPECTIN CONTENTS OF RICE AND THEIR INFLUENCE ON THE COOKING QUALITY OF THE CEREAL. Indian Acad. Sci. Proc. 36B: 70-80.
- (72) REYNOLDS, E. B.
1954. RESEARCH ON RICE PRODUCTION IN TEXAS. Tex. Agr. Expt. Sta. Bul. 775, 29 pp.
- (73) RYKER, T. C.
1943. PHYSIOLOGIC SPECIALIZATION IN *CERCOSPORA ORYZAE*. Phytopathology 33: 70-74.

- (74) RYKER, T. C.
1947. NEW PATHOGENIC RACES OF *CERCOSPORA ORYZAE* AFFECTING RICE. (Abstract) *Phytopathology* 37: 19-20.
- (75) ——— and COWART, L. E.
1948. DEVELOPMENT OF *CERCOSPORA*-RESISTANT STRAINS OF RICE. (Abstract) *Phytopathology* 38: 23.
- (76) SCOTT, J. E., WEBB, B. D., and BEACHELL, H. M.
1964. RICE TEST-TUBE MILLER. *Crop Sci.* "Brief Articles" 4: 231.
- (77) ——— WEBB, B. D., and BEACHELL, H. M.
1964. SMALL SAMPLE RICE POLISHING MACHINE. *Crop Sci.* "Brief Articles" 4: 232.
- (78) SMITH, W. D.
1955. THE USE OF THE CARTER DOCKAGE TESTER TO REMOVE WEED SEEDS AND OTHER FOREIGN MATERIAL FROM ROUGH RICE. *Rice Jour.* 58(9): 26-27.
- (79) ———
1955. THE USE OF THE MCGILL SHELLER FOR REMOVING HULLS FROM ROUGH RICE. *Rice Jour.* 58(10): 20.
- (80) ———
1955. THE USE OF THE MCGILL MILLER FOR MILLING SAMPLES OF RICE. *Rice Jour.* 58(11): 20.
- (81) ———
1955. THE DETERMINATION OF THE ESTIMATE OF HEAD RICE AND OF TOTAL YIELD WITH THE USE OF THE SIZING DEVICE. *Rice Jour.* 58(12): 9.
- (82) TODD, E. H., and BEACHELL, H. M.
1954. STRAIGHTHEAD OF RICE AS INFLUENCED BY VARIETY AND IRRIGATION PRACTICES. *Tex. Agr. Expt. Sta. Prog. Rpt.* 1650, 3 pp.
- (83) WARTH, F. J., and DARABSETT, D. B.
1914. THE FRACTIONAL LIQUEFACTION OF RICE STARCH. *Mem. Dept. Agr. India, Chem. Ser.* 3: 135-147.
- (84) WAYNE, T. B.
1930. MODERN RICE MILLING AS PRACTICED IN THE WORLD'S LARGEST COMPLETE MILL. *Food Indus.* 2: 492-495.
- (85) WELLS, D. G., and CAFFEY, H. R.
1956. SCISSOR EMASCULATION OF WHEAT AND BARLEY. *Agron. Jour.* 48: 496-499.
- (86) WILLIAMS, F. J.
1957. AT THE RICE BRANCH EXPERIMENT STATION . . . A NEW SEED PROCESSING PLANT. *Ark. Farm Res.* 6(5): 2.
- (87) WILLIAMS, V. R., WU, W. T., TSAI, H. Y., and BATES, H. G.
1958. VARIETAL DIFFERENCES IN AMYLOSE CONTENT OF RICE STARCH. *Agr. Food Chem.* 6(1): 47-48.
- (88) WISE, L. N.
1954. RESEARCH IN SEED PROCESSING. *Amer. Soc. Agron. 1954 Annual Meetings Agron. Abs.*, p. 91.

SOILS AND FERTILIZERS

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Types of Soils Used for Rice Production

Rice, a semiaquatic plant, must be maintained under flooded conditions during part or all of the growing season to minimize weed competition and to provide high yields. Because of these water requirements, the ideal soil types for rice production are those that conserve water. Usually clay and clay loams, silty clay loams, or silt loams are considered most desirable. Soils with a high clay and silt content provide conditions for slow water percolation. Other soils, including organic soils, can be used if they possess a hardpan or claypan capable of maintaining up to 8 inches of floodwater. Rice soils should be capable of easy surface drainage also, since many aspects of mechanization require removal of the surface water.

Apart from the aspects of water conservation, light-textured clay and silt soils are generally preferred because of their generally favorable fertility and chemical and physical properties conducive to the satisfactory growth of rice. These soils, when drained, adequately support the mechanical equipment used in rice production. Soil requirements for rice are not demanding, but the soil should be fertile and capable of satisfactory management.

Rice does not have a critical soil pH requirement, although the best producing soils have values between 5.5 and 6.5. In this range of pH values, nutrient availability is generally good; and toxicities from such things as aluminum, iron, sulfides, and sodium do not generally occur. The soil pH in the rice root zone normally increases from 0.5 to 1.5 pH units when placed under flooded conditions, and it decreases when the excess water is removed. This increase of pH influences the uptake of nutrients and plant development. Use of some fertilizers, particularly prolonged use of ammonium nitrogen sources, increases soil acidity. It is not uncommon for soil pH to decrease as much as 2 pH units where ammonium nitrogen sources have been used in rice production for 15 to 20 years.

Salinity problems are sometimes encountered in areas where soluble salts have accumulated or where a poor quality of irrigation water is used. Sea water that is intruded into rivers and waterways or that is brought in by storms of hurricane force may be a source of excess salinity.

Because rice can grow in flooded soils, it is occasionally used as a reclamation crop. Varieties differ in tolerance to salinity, but all are affected by the salt concentration of the soil solution in the root zone. The effects of salinity on rice depend somewhat on its stage of development when it is exposed to saline conditions. Studies of salinity effects indicate that rice is most tolerant during germination and is most sensitive during the 1- to 2-leaf stage. Salt tolerance apparently increases during the tillering and elongation stages but decreases during the flowering stage. Results of field experiments have indicated that high soil salinity occurring at planting time may seriously impair yield by reducing germination and stand establishment.

Most rice soils, often referred to as heavy soils because of their high clay and silt content, present special management problems. These include tillage and seedbed preparation, maintenance of organic matter and soil structure, adequate drainage for essential mechanized rice operations and for other crops planted in rotation, green manure crops, fertilizer application, and weed control. Management of rice soils is discussed in the section "Culture," p. 74.

The soils most widely used in rice production in the United States are of alluvial origin (32).¹ Brief descriptions of the soils used for rice in the principal rice-growing States are given below.

Arkansas

Crowley silt loam, Calhoun silt loam, and Sharkey clay are the principal soils used for rice production in Arkansas (21). Other soils are sometimes used.

CROWLEY SILT LOAM.—The surface of Crowley silt loam is gray to brown. It is underlain with a gray or yellowish-gray silt loam that changes with depth into a gray silty clay and finally into a heavy clay usually mottled with yellow and red. Crowley silt loam in its virgin state has a fairly high organic matter content, but it is low in phosphorus and is strongly acid.

CALHOUN SILT LOAM.—Calhoun silt loam is a

¹ Italic numbers in parentheses refer to Selected References, p. 72.

light gray to almost white shallow soil underlain with a compact drab or yellowish-drab clay. This soil is common in lowlands in eastern Arkansas. Calhoun silt loam is low in total nitrogen and phosphorus, and it is acid to strongly acid. Rice is commonly grown on Calhoun silt loam in the "North-end" of the Arkansas rice area.

SHARKEY CLAY.—The surface soil of Sharkey clay is a dark, drab, or grayish-brown silty clay usually mottled with brown. This is underlain at varying depths with a drab, steel-gray or blue, sticky clay. Sand is frequently found in the surface layer. Sharkey clay occurs commonly in the Mississippi River bottoms. It is known as "buckshot land" because it granulates and forms a crumb structure. It can be plowed when wet; and as it dries out, it breaks down into granules or into clods that are easily slaked by rain. Under natural conditions this soil is poorly drained, and the natural vegetation is hardwood and cypress. In the virgin state it is well supplied with nitrogen and phosphorus, and it is slightly acid to neutral in reaction. In recent years, Sharkey clay has been widely used for rice in the Mississippi Valley.

OTHER SOILS.—Other soils sometimes used for rice production in Arkansas are Waverly silt loam, and Waverly, Miller, and Portland clay soils. Because these soils usually have poor natural drainage, they have come into use for rice production only in recent years.

Louisiana

According to Walker and Miears (35), the principal soils used for rice production in Louisiana are the Crowley, Midland, and Beaumont soils.

CROWLEY SOILS.—Soils of this type found in Louisiana are the same as soils of this type in Arkansas.

MIDLAND SOILS.—The Midland soils, which generally are alluvium deposited by the Red and the Mississippi Rivers, are deep and poorly drained (5). The surface soil is gray to dark gray and strongly acid. The subsoil is strong-brown to light olive-brown, heavy, silty clay mottled with gray. It is very strongly acid to mildly alkaline.

MIDLAND-CROWLEY MIXED SOILS.—Soils that are a mixture of Midland silt loam, Midland silty clay loam, and Crowley silt loam are used for rice in Louisiana. Fertility and organic matter content of the soils are moderate, and surface runoff, infiltration, and permeability are slow (5).

BEAUMONT CLAY.—Beaumont clay soil is acid, poorly drained, and very slowly permeable (28). It occurs mainly in southwest Louisiana and in Texas, east of the Trinity River.

Texas

In addition to Beaumont clay soil which comprises about one-fourth of the riceland in Texas, rice is grown on Lake Charles clay, Bernard clay loam, Edna fine sandy loam, Hockley fine sandy loam, and Katy fine sandy loam (28).

LAKE CHARLES CLAY.—Lake Charles clay is the principal heavy soil in the rice belt west of the Trinity River in Texas. It comprises probably one-third to one-half of the rice acreage around Houston, Angleton, Bay City, and El Campo. Lake Charles clay is darker and more granular than Beaumont clay. It is slightly acid to mildly alkaline in reaction, with a pH of 6 to 8.

BERNARD CLAY LOAM.—Bernard clay loam is similar to Lake Charles clay but is more loamy and slightly less dark, and it occurs on slightly higher elevations. It is found both east and west of the Trinity River in Texas. This soil is slightly acid to neutral in reaction, with a pH of 6 to 7.

EDNA FINE SANDY LOAM.—Edna fine sandy loam has a grayish, sandy surface and is underlain at a depth of 6 to 12 inches by a heavy, gray claypan. It is found principally in the western and southwestern parts of the Texas rice belt.

HOCKLEY FINE SANDY LOAM.—The Hockley soils form a narrow belt along the northern part of the rice area from Cleveland, in Liberty County, westward through Hockley, Sealy, and Eagle Lake to western Victoria County, Texas. These sandy loam soils are underlain by friable, sandy clay subsoils. They are slightly more sloping and better drained than are the Katy soils, and they require more irrigation water than do the Katy soils.

KATY FINE SANDY LOAM.—Katy fine sandy loam occurs in large level areas adjacent to Lake Charles soils and in the flatter portion between the slightly more sloping and better drained Hockley soils.

California

Stockton and Sacramento clay (27) and Wil-lows (14) are the principal soils used for rice production in California. However, several other soils are also used.

STOCKTON SOILS.—Stockton adobe clay is one of the principal soils used for rice culture in California. The surface soil is dark-gray or black clay, 5 to 16 inches deep. When wet, it is dense and plastic, but it shrinks in drying and develops large blocks separated by wide cracks. The upper part of the dark, grayish-brown, heavy clay subsoil is similar in structure and consistency to the surface soil but is calcareous. The subsoil has slightly more colloidal clay and less organic matter than the surface soil.

SACRAMENTO SOILS.—Sacramento clay soil occupies low-lying flood plains and is derived from transported material of mixed geological origin. It was developed under poorly drained, marshy conditions. The dark-gray or dark, brownish-gray surface soil, 14 to 24 inches deep, is coarse and lumpy. It is heavy textured, and contains varying quantities of completely or partly decayed organic matter. The transition to a variable subsoil, made up of stratified layers of mineral and organic soil material, is rather abrupt.

WILLOWS SOILS.—Willow soils consist of stream sediment, usually reddish or yellowish brown or dark brown, deposited along the courses of minor creeks or in the waters of temporary lakes, and underlain by brown to light-brown, compact and relatively impervious subsoils.

OTHER SOILS.—Other California soils frequently used for rice production include Geneva, Meyers, and Yolo of sedimentary alluvial origin; Marvin, Merced, and Sycamore of mixed alluvial origin; and San Joaquin of granitic alluvial origin.

Chemistry of Flooded Soils

In the production of rice, the benefits of flooding the soil are recognized wherever the crop is grown. Senewiratne and Mikkelsen (29) reviewed the literature and provided evidence that flooding enhances foliar development, tillering, and earlier flowering and increases yield of rice when compared with nonflooding irrigated culture. The superior growth of rice under flooded conditions can be attributed in part to the effects of the aquatic environment; but the chemical characteristics of flooded soils are of major importance in the development of the crop.

The most distinguishing characteristic of a flooded soil is the presence of standing water during part or all of the growing season. The layer of floodwater, creating waterlogged conditions, exerts profound changes in the physical, chemical, and biological status of the soil. The immediate effect of flooding is a drastic curtailment of gaseous exchange between the atmosphere and the soil. Water fills the soil pores, reducing oxygen entry and often allowing accumulation of gaseous products of anaerobic decomposition. Carbon dioxide concentrations build up in the flooded soils, together with methane, hydrogen, nitrogen, and various oxides of nitrogen.

Entry of oxygen is not completely restricted but is confined largely to a thin layer of soil at the soil-water interface (23). Oxygen arises from gaseous exchange with the atmosphere and as a product of photosynthesis of phytoplankton and hydrophytes.

Pearsall (24) and Pearsall and Mortimer (25),

working with naturally flooded soils and lake muds, determined that there were significant differences between the soil at the soil-water interface and the soil immediately beneath. Floodwater containing some dissolved oxygen maintained a thin surface layer of soil in an oxidative condition with soil color characteristics and physico-chemical and biological properties different from those of the soil beneath. Oxidation-reduction potentials in the oxidative layer exceeded 320 to 350 millivolts at a pH of 5.0 and contained such oxidized chemical radicals as nitrates, sulfates, ferric, and manganic ions. The underlying soil was conspicuous by the absence of oxygen and the concomitant presence of the reduced forms of chemical radicals such as ammonium, ferrous iron, and manganous manganese; nitrogen gas and its oxides; and various sulfides, including hydrogen sulfide. The oxidation potentials were generally below 350 millivolts at a pH of 5.0 in the reducing layer. Mikkelsen and Finrock (17) showed that reducing conditions in Stockton clay develop about 3 days after a soil is flooded. Patrick and Sturgis (23) showed that when soils are flooded, the soil oxygen disappears within a few hours and may be nearly absent at depths exceeding about one-half inch.

The oxidation-reduction status of the soil under flooded conditions is governed by several factors, including the rate of oxygen exchange, microbial activity, the soil content of decomposable organic matter, and the base saturation status.

Flooding has been shown to increase the soil pH. The increase depends partly on the initial pH value and organic matter content of the soil, and on the period of submergence. The pH increase varies usually between 0.5 and 1.5 pH units. Reed and Sturgis (26) showed that the pH increase in flooded soils they studied varied from 0.82 to 1.55 pH units, depending on soil conditions and initial pH values. Generally, soils with a low pH and with high soil organic matter composition undergo the greatest pH changes when flooded. The cause of the pH increase is not completely understood but has been attributed variously to increased ammonium composition, soluble ferrous, and manganous hydroxides, which neutralize the exchangeable hydrogen ions in the soil.

Another generally observed result of flooding is the increased specific conductance of the soil solution. The phenomenon is well established, but detailed information is lacking on the specific nature of the increased composition of dissolved solids in the soil. The increase in the concentration of ammonium, iron, and manganese ions, and in the bases displaced by these ions from the soil exchange complex may in part

account for the increased specific conductance. The increased composition of carbon dioxide, especially at high pH values, would increase the bicarbonate ion concentration.

Several mechanical properties of soils, including permeability, plasticity, cohesion, and consistency, are changed by flooding. Ordinarily, these changes do not adversely influence the growth of rice. Allison (2) showed that the permeability of a flooded soil is influenced by the amount of air entrapped during submergence. He noted that permeability decreased after flooding but increased again as air trapped in the soil was released. At a later period after flooding, permeability may again decrease if bacteria-produced material blocks the pores and restricts water movement.

Sturgis (31) called attention to possible deleterious effects of flooding on soil structure. He cited evidence that low productivity of some Louisiana soils was caused by deflocculation during flooding. The specific factors associated with the deflocculation were not reported.

In addition to other effects, flooding has an important influence on soil temperature and consequently affects the growth of rice both directly and indirectly. The high specific heat and high heat of vaporization of water prevent its temperature from dropping as fast or as low as does air temperature. Under some circumstances, this modification of the plant environment may enhance the growth of rice.

Upland soils with good aeration usually maintain diverse populations of microflora and microfauna. These organisms decompose organic matter from which they derive energy and liberate carbon dioxide. They exert a heavy demand for nutrients, especially nitrogen, as they produce cellular material. Under flooded conditions, the normal soil complement of actinomycetes, fungi, bacteria, algae, and protozoa is modified to produce a microflora consisting principally of anaerobic bacteria, some facultative anaerobes, and a modified population of algae. The anaerobic forms have a much lower energy requirement than do the aerobic forms and consequently decompose organic matter at a slower rate. The slower decomposition of organic matter under flooded conditions is partly responsible for the development of peat in bogs and marshes. The modification in the soil microflora and microfauna is only temporary, and normal populations develop when drainage and aeration are maintained.

The decomposition of organic matter proceeds at a slower rate in flooded soils than in upland soils, and the end products are different. Tenney and Waksman (33) showed that the decomposition of cornstalks under flooded conditions proceeds at about half the usual rate; and with more

resistant materials, high in lignin, decomposition under flooded conditions is delayed to a much greater extent. In well-drained soils, the end products of organic matter decomposition are principally carbon dioxide, nitrates, and sulphates. Under flooded conditions, the end products include methane, hydrogen, various organic acids, ammonium ions, nitrogen and its various oxides, amines, mercaptans, and hydrogen sulfides.

The rate of organic matter decomposition in soils depends on the kind of organic constituents and their nitrogen content and the carbon-nitrogen ratio. Ordinarily, if nitrogen is adequate for microbial function, nitrogen is mineralized, and if carbonaceous materials are in excess, nitrogen is immobilized. Data from various sources indicate that organic matter decomposition under anaerobic conditions proceeds at lower total nitrogen values than the 1.2- to 1.5-percent nitrogen values established under aerobic conditions and that immobilization of nitrogen does not occur except at higher carbon-nitrogen values than the approximate 15:1 established for well-drained soils. In well-aerated soils, the mineralization of organic matter gradually increases nitrate production. In flooded soils, the mineralization process produces ammonium ions. The number of ammonium ions reaches a plateau value rather rapidly and then declines rather sharply.

The occurrence of two distinct layers—an oxidative layer at the soil-water interface and a reduction layer immediately beneath—exerts a significant influence on agronomic factors associated with rice production. These layers should be taken into account in seedbed preparation, crop residue management, fertilization, cultivation, and water management.

Two types of nitrogen transformations occur in flooded soils, depending on whether oxidizing or reducing conditions prevail. In the thin oxidizing layer at the surface, the nitrogen transformations are similar to those that occur in well-drained soils. Organic matter in this layer is mineralized to ammonium ions and ultimately to nitrate ions by the action of highly specialized autotrophic micro-organisms. The nitrate ions are used by either plants or micro-organisms. They may be immobilized, depending on the carbon-nitrogen ratio of the organic matter; or they may be moved into the underlying reducing zone by leaching. The nitrogen status of the reducing zone is characterized by the denitrification of nitrates and the accumulation of ammonium ions. The ammonium ions that are produced by the more sluggish bacterial microflora are not reduced and provide the reservoir of nitrogen for use by the rice crop. Nitrates that move into or originate in this layer are reduced to nitrites and finally to nitrogen gas or its oxides. These gases ultimately escape into the air. This reduction of

nitrate is favored by low oxygen tensions and the presence of oxidizable organic matter. Janssen and Metzger (10) have amply demonstrated that nitrate nitrogen accumulates in well-drained soils, in contrast with flooded soils where ammonium ions accumulate.

The practical significance of the differentiation of distinct oxidation and reduction layers is apparent in results demonstrating the poor efficiency of nitrate-nitrogen fertilizer sources in continuously flooded soil and the desirability of fertilizer placement of ammonium nitrogen sources (20). Nitrate nitrogen that is applied as a basal fertilizer application or that develops in the oxidation layer is largely lost through leaching and subsequent denitrification. Where reducing conditions develop after flooding, drilling ammonium nitrogen several inches into the soil before flooding provides good retention and availability of the nitrogen for the rice crop (17).

Flooding a soil often provides conditions for the increased availability of both the native phosphorus and that applied as fertilizer. Evidence of this is obtained in both the uptake of phosphorus by rice and the increased solubility of phosphorus, as shown by soil-test extraction methods (13, 20, 30). Factors that appear to be associated with increased phosphorus availability include pH modification, reduction of insoluble ferric phosphate to the more soluble ferrous form, hydration and subsequently increased hydrolysis of ferric and aluminum phosphates, and increased displacement of soluble phosphorus by formation of complex ion and substitution of organic anion.

Sulfur in organic forms or as the sulfate ion is ultimately reduced, at least in part, to sulfides in flooded soils. Sulfate reduction is accomplished by anaerobic bacteria that are active over a wide range of soil pH and operate under low oxidation-reduction potentials. Hydrogen sulfide, the end product of bacterial reduction, may occur free in gases produced in flooded soils and may accumulate in amounts toxic to rice. This occasionally occurs in light-textured soils under extreme reducing conditions and in the presence of large amounts of readily decomposable organic matter. Normally, soils contain sufficient active iron to completely precipitate the sulfide ion as ferrous sulfide.

Iron, a prominent constituent of the soil, occurs in primary minerals, hydrated oxides, silicate clays, and various organic complexes. When a soil is flooded, the iron undergoes considerable changes in solubility, which is greatly influenced by anaerobic bacteria. The extent of the change is also a function of the organic matter content, the low oxidation-reduction potential, and the soil reaction. Ferric iron, which predominates in well-drained soils, is reduced to the ferrous form, especially as hydroxides and carbonates. Decom-

posable organic matter in the soil enhances the reduction process. With sustained flooding, equilibrium develops between the soil and the soil solution, with a significant increase in soluble and exchangeable iron. Both mineral and organic salts of iron appear in the soil solution. Ordinarily, the abundance of soluble iron does not adversely affect the growth of rice; but situations may exist where toxicities or nutrient antagonism may impair growth.

Manganese chemistry of the soil is not well understood. Its forms are dynamic in equilibrium, depending on such factors as pH, oxidation-reduction status, the presence of organic matter, and microbial activity. Manganese occurs in three valence forms, with some compounds containing manganese in two valence forms. In some respects, the behavior of manganese in the soil is similar to that of iron. In flooded soils, the higher oxides of manganese are reduced to soluble and exchangeable ions. Biological reduction occurs independent of soil pH if low oxidation-reduction potentials exist. Decomposing organic matter reduces manganese, especially in the lower soil pH range. It is unusual for soil manganese in flooded soils to affect growth of rice adversely. High levels of soluble and exchangeable manganese in the soil may be toxic to sensitive crops grown in rotation after rice.

Fertilizers

Southern Rice Area

The proper use of fertilizers on rice increases yield from 30 to 50 percent in the southern rice area. Practically the entire rice area in Louisiana and Texas requires additions of commercial fertilizers for economical yields. This is also true with most of the rice soils in Arkansas, particularly in the traditional ricegrowing area of the Grand Prairie region; however, the newer rice bottomland soils in the delta areas of Arkansas and Mississippi may not require fertilizer during the first year or two of rice cropping.

Commercial fertilizers were not used extensively in the southern rice area before World War II. In fact, results from many of the soil fertility tests conducted in the early thirties showed negative yield responses from fertilizer applications (12). This was usually true when various rates and ratios of nitrogen and phosphorus had been applied at seeding. This method of application greatly stimulated weed and grass growth before the rice plants became established, and this competition often severely reduced rice yield. However, the real worth of commercial fertilizers became apparent with the gradual improvement of irrigation and drainage facilities, improved land preparation, mechanized harvesting equipment, the development of varieties suitable for

mechanization, and the greatly increased use of the airplane for applying fertilizers. Fertilizers were also greatly improved. Pelleted or prilled, granular, and large crystalline, high-analysis fertilizers are available and are ideally suited for application with the airplane or with improved ground equipment (1, 3).

Knowledge of previous cropping history and a soil test are useful in determining the amount and kind of fertilizer to use on rice in some Southern States (4, 28). Specific fertilizer recommendations vary considerably between States and from area to area within States, or even from farm to farm within the same area. The rice variety, water management, methods of weed control, and other managerial variables affect use of fertilizers (15). Various rapid, chemical, soil-testing methods are used effectively to determine the fertilizer and lime requirements of rice soils (4). Chemical determination can be made on soil reaction (pH), percentage of organic matter, and the available phosphorus, potassium, and calcium; and the salinity hazard can be noted. The nitrogen level is usually estimated from the organic matter content. Results of these tests obtained from air-dried soil samples can be interpreted with reasonable accuracy, provided basic information is available on the complex chemical changes known to occur under submergence. All this information is of value in determining fertilizer requirements for rice in southern rice areas.

Nitrogen is used at somewhat higher rates in Arkansas than in the other States. Rates above 100 pounds per acre of actual nitrogen are rather common, particularly on the soils of the Grand Prairie (34). Some differences in the fertilizer requirements of rice varieties are recognized, with the stiffer strawed varieties being capable of using and withstanding higher rates of nitrogen without lodging. Phosphorus and potash are usually applied on the basis of a soil test. The nitrogen requirements for rice grown in the delta areas of Arkansas and Mississippi seldom exceed 60 to 80 pounds per acre. These newer soils frequently require no fertilizer during the first year or two of rice production.

The timing of fertilizer application on rice is very important. Most rice farmers in Louisiana and Texas prefer a somewhat earlier application of the total amount of fertilizer than do farmers in Arkansas and Mississippi (34). For all States, however, it is generally conceded that all of the phosphorus and potassium and part of the nitrogen should be applied as near to seeding time as possible. In Louisiana and Texas, the remaining nitrogen should be applied before the rice has completed half of its growth period. In Arkansas, a nitrogen application about 60 to 70 days before harvesting has produced good results. Thus, the timing depends to a large extent on the

total growth period of the particular rice variety.

The rice soils in Louisiana and Texas are generally deficient in phosphorus and in organic matter (35). Thus additions of from 20 to 40 pounds of phosphoric acid per acre and from 40 to 80 pounds of nitrogen per acre are usually necessary for the economical production of rice. In most instances, no potash is required. The small areas of sandy soils in both States, however, sometimes respond to a 20- to 40-pound per acre application of potash.

When applying fertilizer as a topdressing on rice growing in heavy soils, placing it on dry soils is usually preferred to placing it on wet or flooded soils. Soon after the fertilizer is applied, the fields are flooded; thus the water is an effective carrier to move the fertilizer into the root area. If scarcity of irrigation water, weed infestations, rains, or timing difficulties prevent flooding, the rate of application, particularly of nitrogen, is increased slightly to compensate for reduced efficiency. The rate for nitrogen should be increased about 5 to 10 percent on wet soils and perhaps 10 to 15 percent on flooded soils (28).

Applying a large amount of fertilizer directly with the seed is hazardous, since germination may be reduced or emergence may be delayed. The time of seedling emergence directly influences the flooding date and thus becomes important in controlling grass weeds. These problems do not ordinarily occur if the fertilizer is placed 2 to 3 inches below the seeds.

Limited research on the mineral deficiency symptoms of rice has been conducted in the United States. Olsen (22) reported typical foliar symptoms due to deficiencies of nitrogen, phosphorus, potassium, calcium, magnesium, and iron in three greenhouse experiments. A deficiency of each of these elements, except calcium, reduced tillering. Reduced tillering caused by nitrogen deficiency was particularly pronounced. All elements reduced root and top development; potassium and nitrogen deficiencies caused the most severe reductions.

The sources of nitrogen, phosphorus, and potassium used in southern rice areas vary widely and to a large extent depend on the cost of application and physical condition of the fertilizer.

Ammoniacal forms of nitrogen are generally preferred to the nitrate forms; however, compounds containing both sources, such as ammonium nitrate or mixtures of ammonium nitrate and urea in liquid form, are considered equal on an equivalent nitrogen basis to such materials as ammonium sulfate, ammonium phosphate, urea, and ammonium chloride. Because of the lower cost of application, there is a definite trend toward the use of high-analysis fertilizers. Anhydrous ammonia is a good source of nitrogen for rice, although it is difficult to apply with ground

equipment during wet periods. Application in water is satisfactory only when precise watering methods are used, since uniform distribution of the material depends on having a uniform distribution and depth of water.

Phosphorus is usually supplied in the form of superphosphate (either 20 or 46 percent) ammonium phosphate, or diammonium phosphate. Rock phosphate is sometimes used and is satisfactory.

Muriate of potash (KCl) is the common source of potassium. Only limited quantities of potassium sulfate are used, although it is considered equal to muriate of potash.

In areas where crops preceding rice have been fertilized with phosphorus and potash, residual amounts of these elements may be sufficient for one or perhaps two consecutive rice crops.

Research has been conducted with minor elements; however, no positive effects on yields or milling quality have been reported.

Addition of limestone has not been necessary for rice grown on moderately to slightly acid (pH 5.0 to 6.5) soils. Of equal importance is the fact that no detrimental effects on rice yields have been noted from adding lime, which is usually added at the rate of 1 to 2 tons per acre on crops rotated with rice.

The long growing seasons in southwestern Louisiana and southeastern Texas permit the production of a ratoon or stubble crop, particularly by the earliest maturing rice varieties seeded around the middle of April. Research in Texas (8) has shown that for best results, additional nitrogen, usually about three-fourths of the amount applied to the first crop, should be applied immediately after first harvest. This practice consistently gave rice yields that were one-third to one-half as much as the original crop. Ordinarily, fertilizers containing phosphorus and potassium need not be applied, since residual quantities of these elements applied to the first crop fulfill the ratoon requirements.

California

Fertilizers, particularly nitrogen, increased rice yields in the earliest experiments conducted in California, in 1914-16 (11). Dunshee (7) continued rice fertilizer research, and it was greatly expanded by Davis and Jones (6) from 1925 through 1937. They showed that nitrogen fertilizers improved yields significantly on Stockton clay adobe. Applications at the time of seeding were more effective than were later applications. They also reported that phosphate and potassium fertilizers did not increase yields on Stockton clay adobe.

More recent fertilizer research has demonstrated the need for nitrogen on all soils except those on which a good leguminous green manure

crop is grown (18). Phosphorus fertilizers have increased yields on the brownish-red terrace soils bordering the Sacramento and the San Joaquin Valleys. Some basin soils after years of cropping produce better rice yields when phosphorus is included with nitrogen. In some areas, usually parts of large fields, where alkali salts have accumulated and where the soil reaction exceeds pH 8.5 in a 1:10 soil-water paste, dramatic responses have been obtained from various iron sources (9).

Rice was fertilized in California before 1953 by broadcasting either on the dry seedbed before flooding and planting or, more commonly, on the water by airplane after seeding. Fertilizer placement work of Mikkelsen and Finrock (17) demonstrated that nitrogen broadcast on the soil surface or applied to the flooded fields was not used efficiently by rice. Broadcast nitrogen was lost through nitrification and subsequent denitrification. However, ammonium nitrogen drilled 2 to 4 inches into the soil, where reducing conditions developed 3 to 5 days after flooding, remained in the soil and was continuously available to the rice plants.

The time of applying fertilizer before flooding is important, since nitrification is known to be undesirable both before and during flooding. Mikkelsen (16) established that nitrification occurs if ammonium nitrogen is drilled into a warm, moist, aerated seedbed before flooding. As much as 60 percent of the ammonium nitrogen can be converted to nitrate in 7 days of typical spring soil temperatures.

Split application of nitrogen, with part placed in the soil before flooding and the rest used as a topdressing during the period of panicle formation, has proved effective in some regions of the world. Topdressing experiments in California rice production have shown no superiority over preplant soil application (19). Where the seedbed application of nitrogen was not sufficient to maintain normal color and growth of rice, supplemental applications have been profitable. For effective use of topdressed nitrogen on California rice varieties, the application should be made no later than 50 to 60 days after planting.

Phosphate fertilizer should be applied before flooding, usually simultaneously with nitrogen. Phosphorus does not move appreciably from where it is applied; this makes placement in the root zone of great importance.

The quantity of nitrogen fertilizer used in rice production varies from 30 to 120 pounds of actual nitrogen per acre. This is supplied as one of the commercially available ammoniacal sources such as ammonium sulfate, urea, anhydrous ammonia, or ammonium phosphate sulfate mixtures. On soil low in nitrogen, as much as 80 to 120 pounds of nitrogen per acre (400 to 600 pounds of ammo-

mium sulfate) is often used. Soils of average fertility, producing about 50 hundredweight of paddy rice, usually receive applications of 60 to 80 pounds of actual nitrogen.

On most California rice soils, applications of 40 to 60 pounds of actual P_2O_5 per acre will supply the phosphorus needs of rice. Some residual effects have been observed on subsequent crops, but the carryover from a single application may not be sufficient for best yields during a second year. In areas where phosphorus is needed, the added growth and yield often require that additional nitrogen be supplied. Where rice produces better growth with phosphorus, it is generally advisable that nitrogen rates be increased 25 to 50 percent.

Experiments to determine the best nitrogen sources for rice have been conducted over a long period. Davis and Jones (6) compared ammonium sulfate, Ammo-Phos, Leunasalpeter, urea, Ammo Phos Ko, Leunaphos, Calurea, and cyanamide during 1932-36. They concluded that ammonium sulfate was the most profitable. Experiments in which nitrogen from different sources was drilled into the soil before flooding are reported by Mikkelsen and Miller (19). In yield comparisons with ammonium sulfate rated as 100, ammonium chloride ranked 97, cyanamide 92, urea 90, aqua ammonia 85, anhydrous ammonia 83, and ammonium nitrate 57. Aqua ammonia and anhydrous ammonia are good nitrogen sources but in loose dry seedbeds they sometimes do not perform as well as do dry materials because of volatilization losses.

Ingebretsen and others (9) reported that in alkali spots where rice ordinarily died soon after emergence, broadcast applications of ferric sulfate corrected iron deficiency and produced excellent yields. Subsequent tests with other materials indicated that iron oxide, modified and natural iron sulfides, and ferrous sulfate likewise corrected the deficiency. Usually 125 to 250 pounds of actual iron from these sources corrects the iron deficiency.

Selected References

- (1) ADAIR, C. R., and ENGLER, KYLE.
1955. THE IRRIGATION AND CULTURE OF RICE. In Water, U.S. Dept. Agr. Yearbook of Agr., pp. 389-394.
- (2) ALLISON, L. E.
1947. EFFECT OF MICROORGANISMS ON PERMEABILITY OF SOIL UNDER PROLONGED SUBMERGENCE. Soil Sci. 63: 439-450.
- (3) BEACHELL, H. M.
1959. RICE. In Matz, S. A., ed., The Chemistry and Technology of Cereals as Food and Feed, pp. 137-176. Avi Pub. Co., Inc., Westport, Conn.
- (4) BEACHER, R. L.
1955. SAMPLING AND ANALYSIS OF PADDY SOILS. Internatl. Rice Comm. Meeting Proc., FAO, Penang, Malaya.
- (5) CLARK, H. L., HALEY, G. J., HEBERT, E. J., and others.
1962. SOIL SURVEY OF ACADIA PARISH, LOUISIANA. U.S. Soil Conserv. Serv. in coop. La. Agr. Expt. Sta. Ser. 1959 No. 15, 57 pp.
- (6) DAVIS, L. L., and JONES, J. W.
1940. FERTILIZER EXPERIMENTS WITH RICE IN CALIFORNIA. U.S. Dept. Agr. Tech. Bul. 718, 21 pp.
- (7) DUNSHEE, C. F.
1928. RICE EXPERIMENTS IN THE SACRAMENTO VALLEY, 1922-1927. Calif. Agr. Expt. Sta. Bul. 454, 14 pp., illus.
- (8) EVATT, N. S., and BEACHELL, H. M.
1962. SECOND-CROP RICE PRODUCTION IN TEXAS. Tex. Agr. Prog. 8(6): 25-28.
- (9) INGEBRETSSEN, K., MARTIN, W. E., VLAMIS, JAMES, and JETER, ROY.
1959. IRON DEFICIENCY OF RICE. Calif. Agr. 13: 6-7, 8, and 14.
- (10) JANSSEN, GEORGE, and METZGER, W. H.
1928. TRANSFORMATION OF NITROGEN IN RICE SOIL. Amer. Soc. Agron. Jour. 20: 459-476.
- (11) JONES, J. W.
1923. RICE EXPERIMENTS AT THE BIGGS RICE FIELD STATION IN CALIFORNIA. U.S. Dept. Agr. Dept. Bul. 1155, 60 pp., illus.
- (12) ———, 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.
- (13) MCGREGOR, A. J.
1953. PHOSPHATE MOVEMENT AND NATURAL DRAINAGE. Jour. Soil Sci. 4: 86-97.
- (14) MANN, C. W., WARNER, J. F., WESTOVER, H. L., and FERGUSON, J. E.
1911. SOIL SURVEY OF THE WOODLAND AREA, CALIFORNIA. U.S. Dept. Agr., Bur. Soils, Soil Survey Adv. Sheet 1909, 57 pp.
- (15) MIEARS, R. J.
1958. FERTILIZER AND CULTURE PROBLEMS. Rice Tech. Working Group Proc. 8: 17-19.
- (16) MIKKELSEN, D. S.
1962. NITROGEN FERTILIZATION OF JAPONICA RICE IN CALIFORNIA. Rice Jour. 65(3): 8-13.
- (17) ———, and FINFROCK, D. C.
1957. AVAILABILITY OF AMMONIACAL NITROGEN TO LOWLAND RICE AS INFLUENCED BY FERTILIZER PLACEMENT. Agron. Jour. 49: 296-300.
- (18) ———, FINFROCK, D. C., and MILLER, M. D.
1958. RICE FERTILIZATION. Calif. Agr. Expt. Sta. Ext. Serv. Leaflet 96, 12 pp., illus.
- (19) ———, and MILLER, M. D.
1963. NITROGEN FERTILIZATION OF RICE IN CALIFORNIA. Calif. Agr. 17: 9-11.
- (20) MITSUI, SHINGO.
1954. INORGANIC NUTRITION, FERTILIZATION AND SOIL AMELIORATION FOR LOWLAND RICE. 107 pp. Yokendo Ltd., Tokyo.
- (21) NELSON, MARTIN, SACHS, W. H., and AUSTIN, R. H.
1923. THE SOILS OF ARKANSAS. Ark. Agr. Expt. Sta. Bul. 187, 83 pp., illus.
- (22) OLSEN, K. L.
1958. MINERAL DEFICIENCY SYMPTOMS IN RICE. Ark. Agr. Expt. Sta. Bul. 605, 11 pp.
- (23) PATRICK, W. H., JR., and STURGIS, M. B.
1955. CONCENTRATION AND MOVEMENT OF OXYGEN AS RELATED TO ABSORPTION OF AMMONIUM AND NITRATE NITROGEN BY RICE. Soil Sci. Soc. Amer. Proc. 19: 59-62.
- (24) PEARSALL, W. H.
1938. THE SOIL COMPLEX IN RELATION TO PLANT COMMUNITIES. I. OXIDATION-REDUCTION POTENTIALS IN SOILS. Jour. Ecol. 26: 180-193.

- (25) PEARSALL, W. H., and MORTIMER, C. H.
1939. OXIDATION-REDUCTION POTENTIALS IN WATER-LOGGED SOILS, NATURAL WATERS AND MUDS. *Jour. Ecol.* 27: 483-501.
- (26) REED, J. F., and STURGIS, M. B.
1939. CHEMICAL CHARACTERISTICS OF THE RICE AREA OF LOUISIANA. *La. Agr. Expt. Sta. Bul.* 307, 31 pp.
- (27) RETZER, J. L., GLASSEY, T. W., GOFF, A. M., and HARRADINE, F. F.
1951. SOIL SURVEY OF THE STOCKTON AREA, CALIFORNIA. U.S. Dept. Agr. in coop. Univ. Calif. Agr. Expt. Sta. Ser. 1939 No. 10, 121 pp.
- (28) REYNOLDS, E. B.
1954. RESEARCH ON RICE PRODUCTION IN TEXAS. *Tex. Agr. Expt. Sta. Bul.* 775, 29 pp.
- (29) SENEWIRATNE, S. T., and MIKKELSEN, D. S.
1961. PHYSIOLOGICAL FACTORS LIMITING GROWTH AND YIELD OF *ORYZA SATIVA* UNDER FLOODED CONDITIONS. *Plant and Soil* 14: 127-146.
- (30) SHAPIRO, R. E.
1954. THE EFFECT OF FLOODING ON AVAILABILITY OF SOIL PHOSPHORUS YIELD, AND PHOSPHORUS AND NITROGEN UPTAKE BY RICE. Fourth Internatl. Rice Comm. Proc., Tokyo. [Mimeographed paper.]
- (31) STURGIS, M. B.
1936. CHANGES IN THE OXIDATION-REDUCTION EQUILIBRIUM IN SOILS AS RELATED TO THE PHYSICAL PROPERTIES OF THE SOILS AND THE GROWTH OF RICE. *La. Agr. Expt. Sta. Bul.* 271, 37 pp.
- (32) ————
1957. MANAGING SOILS FOR RICE. *In Soil*, U.S. Dept. Agr. Yearbook of Agr., pp. 658-663.
- (33) TENNEY, F. G., and WAKSMAN, S. A.
1930. COMPOSITION OF NATURAL ORGANIC MATERIALS AND THEIR DECOMPOSITION IN THE SOIL. V. DECOMPOSITION OF VARIOUS CHEMICAL CONSTITUENTS IN PLANT MATERIALS, UNDER ANAEROBIC CONDITIONS. *Soil Sci.* 30: 143-160.
- (34) THOMPSON, L., MAPLES, R., WELLS, J., and others.
1962. RECOMMENDATIONS FOR RICE FERTILIZATION IN SOUTHERN STATES. *Rice Jour.* 65(1): 5, 6, and 40.
- (35) WALKER, R. K., and MIEARS, R. J.
1957. THE COASTAL PRAIRIES. *In Soil*, U.S. Dept. Agr. Yearbook of Agr., pp. 531-534.

CULTURE

By T. H. JOHNSTON and M. D. MILLER

Rice has been grown as a commercial crop in the United States since the latter part of the 17th century. Rice cultural methods used from that time until the present have been reviewed by Adair, Miller, and Beachell (8).¹ They traced the evolution of cultural methods from the use of hand labor for clearing timber from the land, for digging canals and ditches, for plowing with a hoe, for seeding, harvesting, and threshing, through the use of animal power (oxen, mules, and horses) for binding and threshing the rice. Then came steam-powered threshers. Today, several large "rice-special" diesel- and gas-powered tractors and self-propelled combines may be used on one farm. Much of the seeding and most of the fertilizing and spraying is now done by airplanes that can cover several hundred acres a day.

Much of the increase in rice production per acre can be attributed to improved cultural methods made possible by the invention and manufacture of the specialized equipment. The major rice areas of the United States are now described as the most highly mechanized farming areas in the world.

Along with improvements in machinery and farming methods have come other innovations, including use of reservoirs for improved water supply and, more recently, underground pipelines to eliminate many open canals.

Rotation or cropping systems; land leveling and seedbed preparation; seed and seeding; irrigating (fig. 28); and harvesting, drying, and storing methods have been developed and improved through research. Many branches of science have contributed to the development and adaptation of new and improved methods, equipment, and facilities now used in rice culture.

Rotation or Cropping Systems

In most rice-producing areas of the United States, crops are rotated because under continuous cropping the soil usually becomes depleted in fertility and in organic matter. The resulting deterioration of the physical condition of the soil makes seedbed preparation especially difficult. In addition, the soil usually becomes progressively

¹ Italic numbers in parentheses refer to Selected References, p. 106.



FIGURE 28.—A ricefield showing the canal that supplies the irrigation water.

infested with weeds and diseases that lower the yield and quality of the rice.

In the early years in the Carolinas, rice was grown continuously in the same field with only occasional rest (44). Later, ricefields in that area sometimes were planted to oats in the fall, followed by potatoes the next year. Some farmers grew rice and cotton in alternate years. This helped to control weeds in both crops.

In the early years in the South Central States, fields were cropped to rice year after year until the rice yields became low and the quality poor because of the mixtures of weed seed and red rice in the threshed grain. Fields then were allowed to lie idle for 1 or 2 years, and then were again put back into rice. This helped to increase rice yields but did not control the weeds satisfactorily. Therefore, ricefields were grazed during the years that they were "laid-out." This practice helped to control grass and weeds but did not control red rice. Some farmers practiced summer-fallowing for a year or two between rice crops and in this way controlled weeds and red rice more effectively than when the fields were idle.

Modern riceland cropping systems are based on information gained from controlled experiments and from grower experience. The preferred system for any farm depends on soil type,

local climatic conditions, and economic considerations.

Arkansas

Rotation experiments were begun in 1927 at the Rice Branch Experiment Station, Stuttgart, Ark. Because of the numerous factors known to affect rice yields, many rotations were tried, along with several combinations of delayed seeding, tillage for weed control, and summer-fallowing. Results included the following (93, 94):

(1) In 2-, 3-, and 4-year rotations, best yields were obtained when rice was grown not more than half the time.

(2) Rice rotated with fallow or early planted soybeans (for beans or hay) or lespedeza (for hay) produced 1,000 pounds more rice per acre in the year it was grown than when rice was grown continuously. Over a 7-year period of continuous cropping, rice yields declined 180 pounds per acre.

(3) The best 3-year rotation was 1 year of soybeans, followed by a winter vetch cover crop, and 2 years of rice. Rice yield increase was greatest the first year.

(4) As compared to continuous rice, 4-year rotations of soybeans-oats-rice gave large yield increases in the first year of rice, but only half as large an increase in the second year of rice.

(5) Rice yields were significantly increased by plowing down legume green manure crops, including soybeans, lespedeza, and hairy vetch (*Vicia villosa* Roth) immediately preceding the rice crops. All green manure treatments increased rice yield more than did chemical fertilizer applied to the preceding crop in the rotation.

Simmons (115) reviewed Arkansas rice rotation research, discussing 3-, 5-, 6-, and 8-year systems. These systems involved rice on the land for half of the time or less and soybeans, oats, lespedeza, or hairy vetch the rest of the time.

Perkins and Lund (100) listed ways in which good rotations would benefit the farmer, but cautioned that these rotations would not replace mineral plant food elements such as phosphorus and potassium. They stated that legumes may supply considerable nitrogen, but more nitrogen may be needed. They also stated that rotations will aid in disease and insect control, but other control measures may be required.

In 1947 the order of frequency of crops in the Arkansas rice area was rice, oats, lespedeza, soybeans, corn, and cotton (120). The most prevalent cropping systems on small rice farms in Arkansas were 4 or 6 years long, with rice being grown on the land for 2 or 3 consecutive years (90, 91). These systems included growing rice and leaving the land idle, a rotation of rice, oats, and lespedeza, and a rotation of rice and soybeans. Returns to the operators were slightly

higher with only one-third of the land in rice than with one-half of the land in rice, if other crops such as oats, lespedeza, and soybeans were grown and harvested to supplement income.

Forty percent of the operators of large rice farms followed a cropping system including rice and oats, with the oats in many cases being overseeded with lespedeza; and almost all operators had some fallow and idle land. Approximately 25 percent of the farmers produced soybeans, and about 35 percent produced beef cattle. The second most common rotation was rice-oats-lespedeza-soybeans, with 42 percent of the land being used for rice under this cropping system.

In 1962, the crops most often grown in rotation with rice in Arkansas were soybeans and oats. Legume green manure crops were used infrequently. In recent years, 1 or 2 years of lespedeza in a rice rotation has sometimes led to considerable damage to rice from the so-called lespedeza worm, grape colaspis, *Maecolaspis flavida* (Say). However, chemical controls for this insect have been developed by Rolston and Rouse (107).

The rotation of rice with reservoirs used for fish production and as a source of irrigation water has been practiced in Arkansas (46). In some instances, the rotation has produced substantial increases in rice yields, even without the use of commercial fertilizer on the rice crops. The rotation may include 2 years of fish and 2 years of rice or 1 year of fish and 1 or 2 years of rice. Leaving a reservoir in fish for longer than 2 years is usually unsatisfactory because the accumulated fertility results in excessive vegetative growth of the rice the first year after fish. In some cases, even 2 years in fish results in excessive vegetative growth and severe lodging of the following rice crop.

Experiments by Sims (117, 118) indicate that a large part of the increased vegetative growth of rice may be attributed to the accumulation of ammonium nitrogen in the soil during the period the reservoirs were in water and fish. Excessive vegetative growth of rice may be avoided by growing a row crop such as soybeans, grain sorghum, or corn in the rotation the first year following fish or water and then growing rice the second year. In one field test on a clay soil that had been in fish 2 years, all of these crops reduced the ammonium nitrogen content of the soil from 175 pounds per acre at seeding time to 40 pounds per acre at harvest. Rice grown on the experimental area the second year did not lodge.

In ricefields where high soil fertility resulted in excessive early vegetative growth, draining the fields and allowing them to dry thoroughly before the development of the rice panicles (heads) at the early jointing stage of growth

helped retard later vegetative growth of the rice and helped reduce lodging.

Green (45) reviewed the problems of fish farming and stated that haphazard raising of fish must be supplanted by more scientific production and marketing practices.

Green and White (47) recently have compared three selected 4-year rice rotations in eastern Arkansas. These rotations were fish-fish-rice-rice, soybeans-soybeans-rice-rice, and idle-fallow-rice-rice. Combinations of buffalo and bass were the fish species most commonly stocked. These studies indicated that a total of 881 pounds of buffalo and 181 pounds of bass per acre must be produced and marketed during the 2-year fish period for this system of land management to be as profitable as the soybean-rice rotation. This level of production is considerably higher than that reported by the 35 fish-rice farmers whose operations were included in the study.

Preliminary experiments conducted at the Rice Experiment Station at Crowley, La., showed that good-quality catfish could be produced under conditions similar to those in flooded ricefields without major disease or parasite problems (128). To help answer some of the complex problems encountered in the growing of fish and in the use of fish-rice rotations, a Fish Farming Experimental Station was established in 1961 at Stuttgart, Ark., by the Fish and Wildlife Service of the U.S. Department of the Interior. In cooperation with the University of Arkansas, experiments have been initiated to determine suitable management and fertilization practices (116).

Sullivan (136) reported that some Arkansas farmers in recent years have started to rotate water and crops. Their fields are kept flooded 1 or 2 years and then seeded to rice. According to Sullivan, benefits under this system include increased organic matter content of the soil, improved physical soil characteristics, improved weed control, and improved recreational and wildlife facilities.

Louisiana

Reporting on early experiments in rice production in southwestern Louisiana, Chambliss and Jenkins (19) in 1925 stated: "Good drainage, good tillage, and proper rotation make unnecessary the application of any commercial fertilizer to the Crowley silt loam at the present time." Results obtained at the Crowley Rice Experiment Station from 1913 to 1923, inclusive, showed that rice in rotation with soybeans averaged 2,384 pounds per acre, as compared with 1,243 pounds per acre for continuous rice. Efficient drainage and good tillage, supplemented by the organic matter added to the soil by plowing under mature soybean plant remnants after

harvest, gave greater returns than were obtained from commercial fertilizer applied to the rice crop. In addition, the soil was left in a loose, friable condition, which facilitated the preparation of a better rice seedbed.

Jenkins and Jones (62) in 1944 pointed out that the rice crop, like other cereals, responds to appropriate cultural methods and rotation systems. At the time their experiments were started in 1934, the rice crop normally was grown in alternate years or once in 3 years on land fallowed or left in stubble pasture for 1 or 2 years. In 2-year rotations, the highest yields of rice were obtained following Italian ryegrass, clovers, or stubble pasture. Another experiment demonstrated how other crops grown in the rotation may influence rice yield. The average yield of rice following cotton that had been dusted with calcium arsenate was 30 percent below the yield following cotton that had not been dusted. The reduced yield apparently was due to the adverse residual effect of the calcium arsenate upon the ensuing rice crop. Reed and Sturgis (104) in 1936 showed that arsenic toxicity symptoms in the rice plants are similar to those of straighthead in which case florets may be distorted and seed set may be reduced markedly.

The average yields of cotton and soybeans in a 3-year rotation of cotton, soybeans, and rice were too low to be profitable, and the average yields of rice was slightly less from this rotation than from the better 2-year rotations.

In 4-year rotations consisting of rice 2 years followed either by 2 years of cotton (fertilized and not fertilized) or by 2 years of native pasture (fertilized and not fertilized), the yields of rice were not increased by fertilizing; but the rice following native pasture yielded somewhat more than did the rice following cotton.

In 10-year rotations of 5 successive rice crops following 5 years each in (1) improved pasture, (2) native pasture, (3) corn plus soybeans, or (4) cotton, the 4-year average yield per acre of rice was 2,192 pounds following improved pasture; 2,120 pounds following native pasture; 2,052 pounds following corn plus soybeans; and 1,444 pounds following cotton dusted with calcium arsenate.

On land cropped continuously to rice for 49 years, the average annual yields for successive 5-year periods during the last 30 of the 49 years ranged from 1,102 to 1,440 pounds per acre. Fluctuations in the 5-year average yields apparently were due to variations in climatic conditions and were not the result of depletion of the soil fertility, according to Jenkins and Jones (62).

Walker and Sturgis (141) reported in 1946 that pasture-rice rotation experiments begun in 1938 and conducted on three soil types of the

prairie rice area of Louisiana showed that a 12-month grazing program could be developed. They stated that up to that time the rotation of improved pasture with rice definitely was the best means found of increasing rice yields and of improving the soil productivity of the area. Also, where proper management practices were used, yields of beef from improved pastures exceeded yields from unimproved pastures by more than 150 pounds per acre. In addition, turning under improved-pasture sod ahead of rice crops increased rice yields 1,000 to 1,800 pounds per acre.

Black and Walker (16) reported in 1955 on a 5-year rotation experiment that was established at five locations in Louisiana, from 1946 to 1953, on four soil types. The results of these five experiments substantiated earlier work on pasture-rice rotation in southwest Louisiana. They found that if improved pastures are established, it is desirable to provide contour levees and irrigation during dry periods, so that full benefits can be received from the relatively large investment required to establish improved pastures. Also, it was necessary to obtain a minimum of 3 years' grazing from an improved pasture before planting it to rice, since an improved pasture produces only about two-thirds as much in the first year as in the second and third years, and the initial cost of an improved pasture is fairly high. Black and Walker concluded that in southwest Louisiana a long-time rotation of improved pasture and rice is superior to the more common rotation of 1 year of rice followed by 1 year of native pasture.

Davis, Sonnier, and White (24) in 1963 described an experiment initiated in 1953 to determine the optimum length of time for pasture-rice rotations in southwest Louisiana. Rotations included 1 year native or improved pasture and 1 year rice; 2 years improved pasture and 1 year rice; 3 years improved pasture and 2 years rice; and 4 years improved pasture and 2 years rice. Fertilization practices varied according to needs shown by soil tests and good agronomic practices. In this study, length of rotation and pasture treatment had little effect on yield of rice. This is believed to be the result of using more fertilizer and the fact that existing soil conditions were somewhat better in this experiment than in earlier experiments in the area. Improved pastures in the rotation increased the yield of beef more than 500 percent.

In reporting on an economic appraisal of farm practices and rotation programs on Louisiana rice farms, Mullins (88) in 1954 pointed out that the most common rotation at that time was 1 year of rice and 1 or 2 years of native pasture. Some longer rotations were being used such as rice 2 years and improved pasture 3 or 4 years. In the longer rotations a smaller proportion of the crop-

land was in rice each year, but the increase in rice yields was sufficient to maintain about the same total volume of rice production on the farm.

A rotation of rice for 2 years and temporary pasture for 3 years gave an average rice yield of 2,600 pounds per acre, as compared with 1,950 pounds per acre from rice alternated with native pasture in a 2-year rotation. When rice was grown for 2 years following 3 years of temporary pasture, the estimated average rice yield for the 2 years was about 3,250 pounds per acre. Leaving land in pasture for a fourth year added an additional 150 pounds per acre to this average rice yield. In addition, the quality of rice improved and this, combined with higher production of beef feeding on the temporary pasture, gave substantially higher net return to rice farmers.

Mississippi

Thompson and Waller (137) in 1952 suggested using rotations of rice-soybeans-soybeans or rice-lespedeza (for hay or grazing)-soybeans in Mississippi. As recently as 1962, Anderson and McKie (11) cautioned growers about substantially decreased yields from growing continuous rice and suggested that a field be held out of rice for 2 to 4 years, during which time the weed population should be reduced. Rice was commonly grown 2 years and was followed by fallow or soybeans. Some growers also used wheat and oats in the rotation.

Mullins (89) in 1960 pointed out that in Mississippi rice is grown in the delta area on clay soils. When a relatively short rotation period of 2 to 3 years is used, farmers generally summer-fallow about as much land as they seed to rice. The fallowed land requires little preparation for seeding the next spring. Rice is not grown on the same field for the second year in such rotations, and rotational crops such as soybeans or small grains usually are omitted.

Some growers use a 5- or 6-year rotation, with rice 2 years and then no rice for 3 or 4 years. When delta rice farmers use longer crop rotation systems, at least half of the rice each year is seeded on land that grew either rice or other crops the previous year. Where rice followed rice, a few operators burned the stubble to facilitate land preparation for the second year of rice. In these longer rotations, the major crop grown in rotation with rice was soybeans. The next most commonly grown crop was wheat. On a small number of farms, oats were grown.

Where adequate surface drainage was available, wheat and oats were well adapted to the clay soils of the rice farms in Mississippi. These small grain crops fit reasonably well into the rice rotation programs. They usually were seeded on

land that had lain idle and had been fallowed the previous summer or on land from which early-maturing soybeans had been harvested. Small grains following soybeans did not always produce satisfactory yields because there was only a short time to prepare a suitable seedbed. This sometimes delayed seeding of small grains and the delay often led to damage from winterkilling. Where the harvesting of small grain was not delayed, it was possible to double crop the land with late-planted soybeans. Because of the risk, some growers preferred to summer-fallow the land before seeding rice or soybeans the following spring.

Missouri

Experiments in Missouri reported by King (74) in 1937 demonstrated that crop rotation was essential to continued high rice yields on Wabash clay (gumbo) soils. In a 6-year period, yields on continuous rice plots dropped to 450 pounds per acre because of infestation with weeds. Rice yields were as high from a 2-year rotation of rice and soybeans as from 4-year rotations that included rice and other crops such as soybeans, wheat, clover, and corn.

Texas

In a review of research on rice production in Texas, Reynolds (105) stated: "High yields of rice have not been sustained by growing rice on the same land every year. Nor has the growing of cultivated crops in rotation with rice proved practical in most of the Texas rice belt."

It is a common practice to grow rice 1 or 2 years and to follow this with several years of grazing beef cattle on volunteer vegetation. Sometimes the land is merely left idle for 2 years or more. When rice follows unimproved pasture or idle land, the improved physical condition and the increased organic matter content of the soil increase rice yields.

Workers at the Beaumont station started research on rotations and cropping systems in 1913. From 1931 to 1941, a number of rotations were tried. The average yields of rice per acre were as follows: continuous rice, 1,072 pounds; continuous rice with fall-seeded sourclover (*Melilotus indica* (L.) All.), 1,194 pounds; rice 1 year and idle 1 year, 1,613 pounds; rice 1 year, fallow 1 year, 1,635 pounds; rice 1 year, cotton 1 year, 1,707 pounds; rice 1 year, soybeans 1 year, 1,618 pounds; rice 1 year, sesbania 1 year, 1,725 pounds; rice 1 year, crotalaria 1 year, 1,642 pounds.

Studies from 1943 to 1945 indicated that rotations of alyceclover for pasture and rice were more satisfactory than were other rotations. Rice following alyceclover produced 2,500 to 2,860

pounds per acre, as compared with 1,800 pounds where the rice did not follow clover. These results led to investigations started in 1946 on the rapid, low-cost conversion from rice to improved pasture in rice-pasture systems.

As reported by Reynolds (105), Moncrief and Weihing found it practical to convert from rice to pasture by broadcasting grass and clover seed, without seedbed preparation, in standing rice at the last draining about 10 days before harvest and in rice stubble after harvest. The levees and drainage ditches used to irrigate and drain the rice were used to irrigate and drain the improved pastures. In the more humid areas a mixture of dallisgrass and clover (Louisiana white, Persian, and large hop) was successful. In drier areas Hubam sweetclover was a more satisfactory legume. It was found that bermudagrass usually volunteered. Ryegrass, tall fescue, and cereals were seeded successfully at the last draining of the ricefields and in the rice stubble. Lespedeza could be established by broadcasting the seed in rice stubble in late February or early March.

Rice yields following improved pastures were increased by 20 percent or more. In addition, as much as 200 pounds of annual beef gains per acre were obtained on the improved pastures, as compared with less than 50 pounds on unseeded, unfertilized pasture fields. The clovers and bermudagrass, and sometimes dallisgrass, volunteered after the rice crop to provide grasses and legumes for the next pasture period. In some cases, pasture seed and hay could be harvested from these fields.

In summary, Reynolds (105) stated: "The several possible rice-pasture systems of farming have not been fully evaluated. However, such systems as 2 years rice, 3 years pasture; 2 or 3 years rice, several years pasture; 1 year rice, 2 to 3 years pasture seem to be worth considering in systems to maintain and improve soil tilth and productivity between rice crops, as well as for providing year-long grazing of nutritious forage for beef cattle on rice farms."

In a report on their studies of year-long grazing in the rice-pasture system of farming, Weihing, Moncrief, and Davis (146) reported that the unimproved pastures were grazed only 201 days during the year, whereas the improved pastures were grazed the full 365 days. In addition, the carrying capacity of the improved pastures was about three times that of the unimproved pastures from April 14 to November 7, 1949; and gains on the improved pastures were nearly four times those on unimproved pastures. Management practices, including fertilization and inoculation of clover seed, were important in establishing improved pastures.

Evatt and Weihing (33) reported that rice following improved pastures produced 650 to 800 pounds more per acre than did rice following unimproved pastures when equal amounts of fertilizer were used. The rotations included in this study were (1) rice and unimproved pasture in alternate years; (2) improved pasture 3 years, rice, unimproved pasture, rice; (3) improved pasture 4 years, rice 2 years; and (4) improved pasture 5 years, rice 3 years.

Ratooning is the harvesting of a second grain crop from regrowth of the first rice stubble. The practice is only possible when well-adapted short-season varieties are grown and the area enjoys about 280 frost-free days (41). About 35 percent of Texas rice acreage was ratooned in 1963.²

Evatt and Beachell (32) discussed ratoon cropping of short-season rice varieties in Texas. They reported that the technique appears to be a practical means of increasing rice yields, provided varieties that mature the first crop in 100 to 105 days are used. It requires about 70 to 80 days to produce the second crop if all operations are properly executed.

Although ratooning now appears to be a practical and possibly profitable operation in United States areas having a suitable climate, expert management is required. Evatt and Beachell (32) have shown that the stubble of the first crop should be at least 16 to 18 inches high. Leaving a shorter stubble delays recovery. Significant yield increases have been obtained from the ratoon crop by applying up to 120 pounds of nitrogen per acre immediately after the first harvest. The stubble is reflooded when regrowth is 18 to 20 inches high. Using the early variety Nato, these authors reported 4,048 pounds per acre from the first crop and 2,382 pounds per acre from the ratoon harvest, for a total of 6,430 pounds per acre from a single seeding.

California

No clear-cut rotation pattern has yet become established for California riceland (68) for the following reasons:

(1) The soil used for rice production generally is inherently quite fertile. Hence, with the relatively short cropping history as compared with other rice States, soil nutrient depletion, with the exception of nitrogen, has not yet proved a limiting factor.

(2) No serious rice disease has appeared to date to force a rigid crop rotation program for disease control purposes.

(3) The rapidly advancing knowledge of weed control, crop fertilization, and other improved cultural practices has made it possible to crop

ricelands for a period of 3 to 10 years continuously and still obtain increasing yields. In 1920, California's average rice yield was 2,295 pounds per acre; in 1963, it was 4,505 pounds per acre.

A number of cash crops are well adapted for growing in rotation with rice in California. The ones most commonly grown are those providing the best immediate economic advantage. One rotation involves rice; spring- or early summer-plowed fallow; and fall-sown wheat, oats, or oats and vetch. Another includes rice; spring-sown grain sorghum or field beans; and fall-sown wheat, oats, or oats and vetch. Safflower may be grown in rotation with rice but production usually is more successful when this crop is grown the second, rather than the first, year after rice.

Two rotational cash crops are sometimes harvested the same year. Wheat or oats may be followed by irrigated grain sorghum, field beans, or safflower. For successful double cropping on riceland, all operations must be expertly timed.

Other crops used occasionally on the better quality, medium-textured riceland soils include sugarbeets, melons for seed, tomatoes, and alfalfa.

Williams, Finfrock, and Miller (149) reported that purple vetch (*Vicia atropurpurea* Desf.), burclover (*Medicago hispida* Gaertn.), horsebeans (*Vicia faba* L.), and field peas (*Pisum arvense* L.) were commonly used in ricelands for winter-grown cover crop and green manure. They reported that leguminous green manures were grown and turned under on about one-fifth of California's riceland and that the practice is expanding rapidly.

Land Leveling and Seedbed Preparation

Jones and others (69) reported that most land on which rice is grown is comparatively level, with a gentle slope toward the drainage channels. The cost of developing for irrigation lands with from 0.01- to 0.50-percent slope usually is economical. A competent surveyor is employed to locate the irrigation canal, drainage ditches, and field levees. Improper location of canals, ditches, and levees may cause serious losses, since it may result in faulty irrigation and poor drainage. Irrigation canals should be large enough to supply ample water promptly when needed. Drainage ditches should likewise be large enough to dispose of water rapidly.

Land Grading and Leveling

A general discussion of land leveling for irrigation has been published by Bamesberger (14). Technical reports of land grading (land forming) for surface irrigation by Gattis, Koch, and McVey (40) and Marr (82) discuss the factors to consider before land grading is undertaken. These

² EVATT, N. S. Texas A & M University, Beaumont, Tex. 1964. [Correspondence.]



FIGURE 31.—Preparing the seedbed: A, Moldboard plow; B, field cultivator with spike-tooth harrow attached; C, disk harrow.

ally it is not necessary to plow in the spring the fields that were plowed the previous summer or fall, except on poorly drained soil or during seasons of heavy rainfall.

In general, land plowed in the spring should be disked and harrowed as soon as possible after plowing to break up any large lumps and clods, to prevent baking or crusting, and to avoid subsequent difficulty in preparing the seedbed. In

Texas, experience has shown that heavy soils, such as Beaumont clay and Lake Charles clay, generally require more subsequent tillage, such as disking and harrowing, to obtain a desirable seedbed when plowed in the spring than when plowed in the fall or early winter (105).

Usually California ricelands are spring plowed to a depth of 4 to 6 inches, after the stubble of the previous crop has been partly reduced by burning. The straw may be burned if dry weather continues long enough. Spring-plowed soils make a better seedbed if allowed to dry for a week to 10 days after plowing before beginning the final seedbed operations. Davis (26) reported that water-seeded rice germinates better, has more seedling vigor, and produces a heavier crop when sown on a seedbed that is dry during the finishing operations. A seedbed prepared under moist conditions for water seeding induces algae (scum) development, increases weed problems, and frequently results in a poor stand because of poor germination and seedling vigor.

Finfrock and Miller (36) reported that a good winter-grown vetch cover crop aids in drying out riceland soil, thereby making it possible to prepare the seedbed earlier. Cover crops turned under for green manure are usually plowed down with a moldboard or a disk plow. For best results in California, the plant material should be completely covered with 4 to 6 inches of soil, according to Williams and others (148, 149).

Seedbed Preparation as Related to Method of Seeding

Rice may be seeded either by drilling on dry ground, or by broadcast seeding with an endgate seeder or airplane on dry ground or in flooded fields. The final seedbed preparation is influenced by the method of seeding to be used. If fields are to be water seeded, growers sometimes are able to prepare a fairly good seedbed in the late fall or winter and to erect their levees at this time. When this is possible, very little land preparation other than harrowing is necessary in the spring. In the Southern States, if the field is to be dry seeded with a drill or with an endgate seeder or broadcast by airplane, the final preparation of the field includes working over the levees while the field is worked. When rice is to be seeded, the final preparation just ahead of the drill usually is done with a spring-tooth or disk harrow behind which is drawn a spike-tooth harrow. This gives a mellow firm seedbed, and the moisture is held near the surface so the seed usually will germinate soon after seeding without irrigating the field. A roller-packer may be used in order to break up clods before drilling and to firm the soil after drilling to help retain moisture. Usually, the levees are reseeded after

they have been partly rebuilt, and the seed then is covered by the final building of the levees with a levee disk or a pusher-type levee maker.

If rice is to be broadcast seeded on dry ground, the final seedbed preparation leaves the surface rough and somewhat cloddy. The seed usually is covered by a shallow working with a spring-tooth, spike-tooth, or disk harrow. Seed on the levees is covered by the final working with the levee disk or pusher. In most cases, precipitation following seeding is necessary to bring about germination and emergence of the rice seedlings.

If a field is to be water seeded, the final seedbed preparation depends somewhat on soil type. On sandy or silt loam soil, a mellow, firm seedbed similar to that for drilling should be prepared. Levees are constructed and are seeded just before the final working with a levee disk or pusher. The remainder of the field is worked between the levees with a spring-tooth harrow, which leaves fairly deep furrows into which the seeds fall as they settle through the water.

When rice is water seeded on clay or very fine silt loam soil, the seedbed should be fairly rough with a clod size ranging up to 4 inches in diam-

eter. This is done in California by harrowing twice with a heavy spike-tooth harrow followed by dragging with a heavy wooden drag. A rough seedbed helps prevent drifting of water-sown seed. As the clods slake down after flooding and seeding, a fine film of soil may cover the seed. In the South, the levees usually are seeded separately. In California, the levees are considerably higher and larger and are not seeded.

Some farmers have been successful in preparing their land in relatively stale water by drawing spring-tooth or spike-tooth harrows through the fields in the mud or in fairly deep water. Other growers who have attempted this method have found it very unsatisfactory.

Construction of Levees

Ricefields are divided by levees into subfields, called paddies or bays (cuts). Levee construction is an important operation in preparation for growing rice because levees are the key device for regulating water depth in ricefields. They must be located accurately and must be well constructed in order to maintain a uniform depth of water within each paddy (fig. 32).

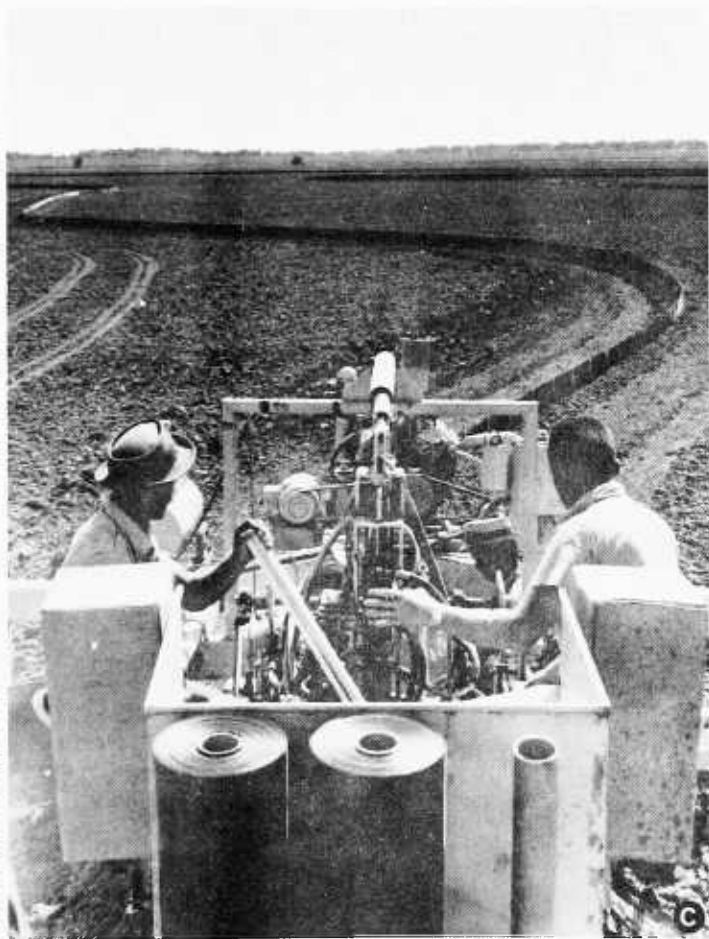


FIGURE 32.—Making levees with (A) disk, (B) pusher, and (C) plastic.

The levees are constructed on the contour, that is, on lines of equal elevation. They should be located by an experienced surveyor or operator who uses an accurate instrument. Because a smooth soil surface is needed for accurate location of the levees, the surveying should be done immediately after the field has been floated. On flat land, the difference in elevation between levees is 0.1 to 0.2 foot, and on steep, sloping land it is 0.3 foot (37, 69). In fields where the levees run parallel to the direction of the prevailing wind, it is desirable, especially if the paddy is large, to build wind levees at right angles to the direction of the prevailing wind. These levees are not tied into the border or contour levees. Their function is to reduce the effect of the wind and thereby decrease wave action and reduce the possibility of levees being washed out.

The levee should be compact and high enough to hold the water at an average depth of 3 to 6 inches in the paddy. In the Southern States, the levees have gently sloping sides, so that they may be crossed with cultivating and harvesting equipment. Here, the levees are completed after the rice is drilled. Levees of this type are considered very efficient, for an entire field can be cultivated, seeded, and harvested as a single unit.

In California, the levees are higher and have steep sides so as to hold a deeper flood; and the areas between pairs of levees must be harvested as a field or unit. This increases farming costs because it increases machinery-maneuvering time. In addition, the land area devoted to high levees is nonproductive.

In the Southern States, the base of the levee commonly is made by plowing one round with a 3-bottom plow. Levees are constructed with a levee disk usually mounted on the rear of a large tractor, or commonly with a single- or double-blade pusher on clay soils. The levee base is built as early as possible, so that it will become compact before flooding time. This is especially important on heavy clay soils on which levee construction often is difficult. Compact, well-settled levees reduce seepage and are less likely to be washed out by excess water from heavy rains. Well-constructed levees, properly repaired after seeding, facilitate irrigation and eliminate much expensive hand shoveling. Much of the work of installing levee gates and closing the gaps at the ends of the levees is done with pickup blades or scoops mounted on small tractors. This eliminates much of the hand labor formerly required.

In California, a V-type diker or soil crowder that is 14 to 16 feet wide in front and 4 feet wide in the back is used to build levees. Two or more heavy-duty, crawler-type tractors are used to pull the diker. The levees usually are from 30 to 36 inches high when freshly made and settle to between 16 to 20 inches. Levees usually are made

in the fall with a base of 5 to 6 feet and are allowed to settle during the winter. A bulldozer or a tractor with a front-end scoop is used to close the gap at the water control boxes and at the end of each levee.

Lewis and others (75) and Scott and others (113) reported on the possibility of using rice levees made of plastic film in lieu of levees made of soil. Their studies show that plastic levees are physically feasible. Their commercial feasibility probably depends on the development of a machine to economically install the plastic levees. Prototype, privately developed machines to install plastic levees mechanically were operated experimentally in California in 1962 and in 1963.

Seed and Seeding

The choice of seed and the use of suitable seeding methods are an important part of rice culture. To achieve a high level of production, the variety to be grown must be adapted for the area. After deciding on the variety, it is necessary to select a lot of rice seed that is free from varietal mixtures, does not contain red rice and weed seed, is high in percentage of viable seed, and has high bushel weight. All rice-producing States now have a rice seed certification program designed to provide high-quality seed for the rice industry.

Before 1941, when combine harvesting, artificial drying, and bulk storage were begun in the southern rice area, there was little incentive to develop a seed rice industry. Varietal mixtures resulting from handling were not serious when binders, stationary threshers, and sack storage were used. Seed rice usually was saved from fields or parts of fields of known varietal purity. Weed seeds and trash were removed by fanning mills and disk or cylinder graders usually owned and operated by private or grower organizations. However, as combine harvesting, artificial drying, and bulk storage developed, varietal mixtures became serious. It was at this time that seed production and processing developed into a specialized business. Today, much of the seed rice sown in the Southern States is given specialized attention during growing, harvesting, drying, and processing. As a result, the seed rice industry is well developed today. Foreign demand for seed of high quality has further stimulated the development of the seed rice industry. Substantial quantities of seed rice are exported annually to Central and South American countries.

Seed Quality

Numerous workers have stressed the desirability of using seed rice of good quality (18, 27, 70, 124). Good seed should be well matured and free from red rice, immature and hulled or broken grains,

seed of other varieties, and weed seeds. The seed should be cleaned and graded to remove hulls, trash, and other foreign matter. Also, good seed should germinate satisfactorily and should produce strong sprouts. Using seed that germinates poorly may result in uneven stands, uneven ripening, and low field yields of poor milling quality.

Smith (124) reported in 1940 that seed lots used on 29 farms were examined, and only 4 were found to be free of weed seeds and red rice. Today, most rice seed is thoroughly cleaned and graded. Consequently, it is free of weed seed and has only a trace of hulled or poorly filled grains.

Much emphasis has been placed on the importance of eliminating red rice from planting seed (2, 70). Red rice is objectionable because the red bran is not completely removed in milling. This results in an unattractive appearance when milled. Also, the grain size, shape, and milling quality are inferior. Red rice tillers profusely and shatters easily, and seeds that have become buried in the soil have been known to remain viable for several years (19, 43). When rice seed containing red rice was seeded several years in succession on the same land and red rice was not controlled, over 50 percent of the harvested grain was red rice (2). In a ricefield in Louisiana, over 500 red rice grains were found in the top 6 inches of each square foot of soil.³

The importance of using seed free from red rice cannot be overemphasized because as long as red rice is being sown, it cannot be eliminated from the fields. Based on a seeding rate of 80 pounds per acre, seed containing 5 red rice grains per pound would probably result in approximately 200 red rice plants per acre. At the Beaumont Rice-Pasture Research and Extension Center, land was cropped 2 consecutive years, in 1946 and 1947, and seed was used that contained approximately two red rice grains per pound. The grain harvested the first year contained about 18 red rice grains per pound and that harvested the second year contained over 125 grains.⁴

Seed rice free from red rice was nearly nonexistent until 10 years ago. Screen graders, which effectively grade seed rice on a grain diameter basis, have been effective in removing the broader red rice grains from long-grain varieties. The screen graders, along with the production and increase of seed stocks free from red rice, have effectively controlled red rice. In a few instances, slender red rice grains that cannot be separated from long-grain varieties have been observed. Whenever a seed lot that contains such types is observed, it should be discarded immediately.

³BAKER, J. B. Louisiana State Univ., Baton Rouge, La. 1963. [Correspondence.]

⁴BEACHELL, H. M. Rice-Pasture Research and Extension Center, Beaumont, Tex. 1963. [Unpublished data.]

Red rice grains are difficult to remove from short- and medium-grain varieties because of the similarity in diameter between those varieties and red rice. Since red rice grains cannot be effectively removed from the medium- and short-grain varieties, it is essential to use seed free from red rice.

The origin of high-quality seed rice and the certification of rice seed is discussed in the section on "Rice Breeding and Testing Methods in the United States," p. 56.

Source of Seed

Jones and others (67) studied the effect of environment and source of seed on yield and other characters of a group of varieties at four rice experiment stations in Arkansas, Louisiana, Texas, and California. They concluded that seed source had no appreciable effect on grain test weight, germination of seed, average grain and kernel weights within a variety, proportion of hulls, and milling quality. In summary, they stated that "local seed of good quality, free of mixtures and weed seed, is as productive as that obtained from other rice-producing States."

Seed Treatment

Finfrock and Miller (36) reported that California growers usually soak their rice seed in a sodium hypochlorite solution at the rate of 1 gallon of household bleach (5.25 percent of NaOCl) per 100 gallons of water. In addition to providing some protection against seedling diseases, the chemical deactivates germination inhibitors located in rice hulls.

Mikkelsen and Sinah (84) reported the presence of six compounds in the hulls of Caloro rice that diffuse into the embryo and inhibit germination when present in large amounts. Compounds identified included vanillic acid, ferulic acid, p-hydroxybenzoic acid, p-coumaric acid, p-hydroxybenzaldehyde, and possibly idoleacetic acid. In low concentrations, these chemical substances stimulate germination and ensuing growth. Leaching the seed by soaking with water reduces the concentration to stimulatory levels. The probable action of sodium hypochlorite solution is to modify these inhibitors so that seedling growth is stimulated.

Garrison (39) reported on work with other small grains conducted by Earhart. Results showed that there is a definite need for all small grain seed to be completely processed, including thorough cleaning and treating. For every 100 field-run seeds put in the ground, only 58 healthy plants were produced. When seed from the same lot was cleaned, 65 healthy plants were produced; and when the seed was both cleaned and treated, 72 healthy plants were produced. Field experiments comprising two rice varieties, sown at two

dates at each of three locations for 2 years, showed an average survival of 61 percent for seed treated with two commonly used seed-treatment chemicals, compared with 52 percent for untreated seed (12).

Information on the treatment of rice seed to prevent seedling blight is given in the section "Rice Diseases," p. 113.

Time of Seeding

Seeding of rice in the United States begins when the weather becomes warm enough for germination and seedling growth. In Arkansas, Mississippi, Missouri, and California, where the growing season is comparatively short, seeding usually is done in April and May, within a period of 3 to 5 weeks. Near the Gulf Coast in Louisiana and Texas, rice can be sown from early March to late June—although most seeding is done in April.

The length of seeding period depends mostly on the length of life cycle of the available varieties. Essentially it is the difference between the length of the growing season for rice in an area and the shortest period of time required to mature a crop.

Seeding time also is influenced, directly or indirectly, by favorable weather conditions for land preparation and seeding operations, methods of seeding, fertilizer practices, availability of fresh water, temperature of water, cold tolerance of varieties, and time of maturity of varieties in relation to date of seeding.

Adair and Cralley (5) stressed that the proper seeding date for each variety is important. They stated that no rice variety should be sown until the mean daily temperature rises to about 70° F. They and Johnston and others (65, 66) reported that because of the relatively long growing period of several of the varieties then available, it was necessary to seed these varieties in Arkansas by late April or early May. Other, shorter season varieties had a wider range of seeding dates. However, when any variety then available was sown in Arkansas after the first week in June, there was a risk that the crop might fail to mature if there was an early frost. However, with the development of the very early-maturing varieties Belle Patna and Vegold, mid-June seedings appear to be relatively safe, even in northern Arkansas. Johnston and others (64) suggested that these two varieties be seeded in northern Arkansas from about June 1 to 10, in central Arkansas from about June 1 to 20, and in southern Arkansas from June 1 to 25. Johnston, Cralley, and Henry (66) emphasized that a relatively "safe" seeding date may depend to a considerable extent on anticipated water management and fertilizer

practices. They pointed out that heavy rates of nitrogen fertilization, particularly when applied late, tend to delay maturity.

Results from date of seeding experiments indicate that there is a comparatively long period in the South during which rice can be sown and still produce satisfactory yields. It is possible and often advisable to spread the seeding time of certain varieties so that the harvest can be extended over a longer period. However, Adair (4), who studied the effect of time of seeding on yield and milling quality in Arkansas, concluded that most of the early and midseason varieties produced rice of better milling quality when they matured late in September or early in October than when they matured before September 15. Jodon (63) stated that since the approximate number of days required from seeding to maturity is known for all commercial varieties, it may be desirable to base the date of seeding on the number of days required for maturity, so that the rice will mature in the fall when the weather is usually dry and pleasant for harvest. Rice maturing after the temperatures have lowered somewhat may be of better milling quality. When rice matures during extremely hot weather, considerable sun checking may result and low head rice yields may be produced when the grain is milled.

Chambliss (18) stated that in the prairie areas of Louisiana and Texas, most of the rice is sown from April 1 to May 15. However, he pointed out that May 1 was approximately the best date for sowing rice on the prairie because of the cold weather that sometimes prevails during April. According to Jones and others (69), rice usually is sown in the Southern States from April 1 to May 30. But if conditions are favorable, some seeding is done in March and as late as June 30. Rice germinates more quickly when sown in the late spring, when temperatures are relatively high, than when sown earlier. Also, late seeding has an advantage in that the weeds that have started growth can be killed by cultivation before seeding of the rice crop.

Reynolds (105) stated that time of seeding rice in Texas ranges from March 1 to late June but that most of the rice acreage is seeded in April and May. He pointed out that the actual time of seeding may depend on several factors, such as the weather, method of seeding, soil condition, and maturity group of the variety. Some varieties can tolerate cool weather in the spring better than others and will thereby produce better stands when seeded relatively early. He further reported that the yield of certain varieties showed a marked decrease when seeding was delayed beyond certain dates. He concluded from tests at Beaumont that the late-maturing varieties should be seeded as early as practicable to insure satisfactory yields.

In California, the period for seeding rice is more concentrated than it is in the South. Some rice is sown in California soon after April 1 and some as late as June 15, but most of it is sown from April 15 to May 15 (36). When rice is sown as late as May 30 in California, it should be fertilized at a moderate rate, and preferably a short-season variety such as Colusa should be grown.

Very early seeding entails certain hazards such as loss of stands due to seedling blight or drowning out of drilled rice. Early growth is slow, prolonging the period from seeding to harvesting. Isolated early-maturing fields may be attacked by concentrations of insects, rodents, or birds. Rice that matures early during hot and dry weather tends to have lower milling quality.

Relatively early seeding in the Southern States helps assure an adequate supply of water to mature the crop before a summertime shortage of water or, in limited areas where it occurs, before the intrusion of salt water. Water is available for early-seeded rice in all areas, although in California the water may be too cold. Early-seeded rice may tiller more, may compete more effectively with weeds, and may escape insects and diseases to some extent. When rice can be harvested early in the season, it usually is possible to avoid seasonal congestion at the driers and to find a ready market. Also, early seeding of short-season varieties usually allows time for the production of a stubble crop in southern Louisiana and Texas. Because of the somewhat shorter growing season and cooler fall temperatures, results and observations indicate that such double cropping (ratoon cropping) is not a safe practice in Arkansas in most years (64).

However, even the customary April seeding often is subjected to unfavorable conditions for establishing stands. Varieties that have short growing seasons mature during hot weather if seeded at the average time, and in some seasons the quality is poor. Localized summer wind storms and rainstorms may cause lodging with resulting loss of yield and increased cost of combining. Often at the peak of the season more rice is ready for harvest than the driers have capacity to process, and the rice that waits in the field is in danger of deteriorating.

Rice matures in a shorter time when sown late than when sown early. Delaying seeding or using varieties that require long growing seasons permits harvesting to be done in the normally cool autumn weather when there may be fewer showers and when the driers are less likely to be crowded. Later maturing rice usually is better quality as long as the temperatures are not too low for normal development of the grain. Delaying seeding also allows time for additional cultivation to reduce weed and red rice infesta-

tion. On land that has been in winter or perennial pasture crops, a delay in date of seeding provides a longer grazing period and makes possible the preparation of a better seedbed.

Late seeding also has disadvantages. There may be a greater possibility of injury by root maggots, armyworms, and stem borers. Weather conditions may be more favorable to the blast fungus at the time the young plants are susceptible. Stem rot may be more severe late in the season. The crop is exposed to early fall storms, likely to be the most damaging of the season. Cold weather may reduce quality and yield if harvest is extremely late. Isolated late-maturing fields probably are more exposed to damage by concentrations of birds and other pests than are extra early fields.

Clearly, there is no ideal time for seeding. In Louisiana and Texas especially, where the seeding period is long and there are several varieties to choose from, the date of seeding demands careful consideration. This is true whether one field is to be seeded to a single variety or a large acreage is to be allotted among two or more varieties.

Rate of Seeding

Factors that enter into a determination of the proper rate of seeding include seed size and quality, condition of the seedbed, fertility of the soil, date of seeding, and variety. In the southern rice area, the seeding rate is about 90 to 110 pounds per acre when drilled and about 115 to 150 pounds per acre when sown broadcast on dry soil or in the water. In California, when rice is sown in the water, seeding rates average about 150 pounds and range from 125 to 200 pounds (dry weight basis) per acre.

The number of rice seeds ranges from 14,000 to 22,000 seeds per pound, depending on the variety. With a seeding rate of 150 pounds per acre, seeds are sown at the rate of about 50 seeds per square foot. Excellent yields have been obtained from populations ranging from 8 to 30 plants per square foot. Seeding rates that provide plant populations between these extremes apparently do not influence yields. Extremely dense stands lodge more readily than do optimum stands. Rice in dense stands heads and matures more uniformly than does rice in thin stands with abundant tillering. Weed control is more difficult in thin stands, so seeding rates should be higher in fields infested with weed seed. Relatively high seeding rates usually are used on land on which many rice crops have been grown previously.

In early tests in Arkansas, Nelson (93) tried 11 rates of seeding, using re-cleaned seed, seeded with a grain drill. The results showed no marked preference for any rate. Although denser stands and fewer weeds were obtained from the higher rates of seeding, higher yields resulted from the

lower rates of seeding. The highest average yields were obtained from sowing approximately 70 pounds of seed per acre.

Simmons (115) reported that later studies at the Arkansas Rice Branch Station at Stuttgart indicated that the best rate for drill seeding was 90 to 110 pounds per acre and that about 110 to 135 pounds per acre was best when the seed was broadcast.

Chambliss (18), reporting on early experiments at the Crowley, La., Rice Experiment Station, found that the largest yields and the best quality of milled rice were obtained from the Honduras variety by drilling 80 pounds of seed to the acre. Other varieties available at that time could be seeded at a slightly lower rate. He pointed out that less seed may be used when the crop is sown in late May if the seedbed is well prepared, since better germination is obtained with higher temperatures prevailing. The quantity to be sown depends on the method of seeding, variety, character of the seedbed, soil fertility, and vitality or germination of the seed. If rice is broadcast on wet land or on a poorly prepared seedbed, the rate of seeding should be increased. If seed of low vitality is used, then the seeding rate should be increased accordingly. Seeding at too low a rate resulted in excessive tillering, irregular ripening, and reduced grain yields.

Reynolds (105) stated that in Texas the rate of seeding ranges from 60 to 125 pounds per acre, with the average about 90 pounds. The rate of seeding varies greatly in different parts of the rice belt of Texas. In the more humid areas, higher rates of seeding are used than in the western counties where rates as low as 60 pounds per acre frequently are used. At Beaumont, from 1914 to 1918, seeding 100 pounds per acre produced slightly higher yields of rough rice than seeding 60 and 80 pounds per acre. Experiments were conducted there from 1950 to 1952 to determine the optimum rate of seeding rice under several levels of soil fertility. Bluebonnet 50 was broadcast at rates of 45, 90, 135, and 180 pounds per acre. Fertilizers were applied on the surface with a fertilizer-grain drill at the time of seeding. There were no significant differences in the average yields of rough rice from the seeding rates of 90, 135, and 180 pounds per acre, but the yields from these rates were significantly higher than those from the 45-pounds per acre rate. As in earlier experiments, the optimum rate of seeding was about 90 pounds per acre. Where weeds are troublesome, heavier rates of seeding usually give better results.

Jones and others (69, 70), summarizing rate of seeding experiments with drilled rice under favorable conditions, indicated that 80 pounds of seed per acre usually is sufficient to give good stands. Yields are seldom materially increased

and sometimes may be reduced if more than 80 pounds per acre is sown. They pointed out that under ordinary conditions, 90 to 100 pounds of cleaned viable seed sown with a drill or 110 to 150 pounds sown broadcast is sufficient to give good stands. They stated that the rate of seeding should be sufficiently high to produce stands that are thick enough to help check weed growth and also to prevent late tillering. The latter often results in irregular ripening and grain of inferior quality.

Method of Seeding

Several methods are used to seed rice in the United States. On dry soil rice may be sown $1\frac{1}{2}$ to 2 inches deep with a grain drill, or broadcast and disked or harrowed to cover. When soil moisture is not sufficient for germination and growth, the field may be flushed. The water is drained immediately because the rice seedling cannot emerge through both 1 to 3 inches of soil and 4 to 8 inches of water. Rice also is broadcast in water by airplanes (fig. 33). Several modifications of the water-seeding method are used. Rice is not transplanted in the United States.

Simmons (115) reported in 1940 that the two methods of seeding being used in Arkansas at the time of his report were the broadcast and the drill methods. The broadcast method had been most popular since it did not require much machinery, and it was used extensively in new rice areas. He pointed out that drilling was being used widely



FIGURE 33.—Airplane being loaded with seed rice, with tanks used for soaking seed in the foreground, and ricefields ready to be seeded on each side of landing strip.

on old riceland. Advantages of drilling over broadcast seeding were that less seed was required for a good stand and that the seed could be put down at a uniform depth and rate, which make a more uniform stand possible. Simmons pointed out that uniform stands are important because they insure even maturity. Grain maturing evenly will have a better grade, and consequently will usually command a better price. He further stated that when rice was seeded with a grain drill, a depth of 1 to 2 inches normally should be used. Deeper seeding sometimes resulted in a poor stand, especially if the soil was clay textured, cold, or inclined to crust after rains.

Jones and others (69) also reported that shallow seeding is preferable to deep seeding on a rough seedbed or a fine mellow seedbed that is inclined to crust after rain. Surface crusts may be broken by a light harrowing or by irrigating to permit the seedlings to emerge.

Nelson (94) reported in 1944 in Arkansas that seeding rice broadcast on the surface of the soil and irrigating immediately gave large increases in yields of rice over the usual method being used at that time. He pointed out that even larger average increases in yield were obtained when the soil was flooded and the seed broadcast in the water. He indicated that both methods could be used to produce higher yields of rice if the practical difficulties involved in seeding large areas by these methods could be overcome. The yield increase apparently was due to the control of grass.

Mullins (89) found that in Mississippi, where ground equipment was common, rice was seeded after the first levee-building operation was performed and before the levees were raised to the desired height. Seeding was done with endgate seeders by approximately 50 percent of the farmers who were surveyed, and grain drills were used by the remainder of those using ground equipment. By 1958, about 20 percent of the farmers seeded some rice in the water with planes, and the practice appeared to be more common in 1959. Water seeding often was used during the later weeks of the planting season when quick germination and effective grass control are particularly important. Some farmers reseeded their levees after the final levee-building operation, but the majority did not.

Reynolds (105) reported that a depth of 1 to 2 inches was best when rice was seeded with a grain drill. In experiments conducted at Beaumont, Tex., from 1914 to 1918, placing the seed 2 inches deep produced slightly higher yields of rice than placing the seed 1 or 3 inches deep. There usually was less rotting from shallow seeding than from deep seeding, especially if irrigation was necessary to germinate the rice seed. Seed could be planted deeper on sandy soils, such as Katy

and Hockley soils, than on clay soils, such as Beaumont clay and Lake Charles clay.

Reynolds (105) pointed out that rice usually was seeded in Texas with a grain drill but that aerial seeding was increasing rapidly and that 110,000 acres were seeded by plane in 1953. He stated that broadcast seeders were used to some extent. On rough, dry seedbeds, rice frequently was broadcast with endgate seeders or with a drill with the disks removed. In either case, the land was then harrowed after seeding and was irrigated. When seeding was done on dry land, fields usually were harrowed after seeding and then flushed to bring about germination. The fields were resubmerged in time to control the growth of weeds and grass.

The seeding of rice in water was started in California as a way to control barnyardgrass (*Echinochloa* spp.) (6). At first rice was sown with a tractor-drawn endgate broadcast seeder, but this method was not very satisfactory. Airplane seeding was attempted first near Merced, Calif., in 1929, for reseeding a field of rice. A fair stand of rice and a satisfactory yield were obtained. Several growers in California seeded their rice from an airplane in 1930. Now airplane seeding is the common practice on California's 300,000 acres of rice.

According to Finckle and Miller (36), the usual practice in California (1964) is to soak the seed for 18 to 24 hours in a sodium hypochlorite solution (see "Seed Treatment," p. 85), drain for 24 to 48 hours, and seed by airplane into fields that have just been flooded to a depth of 6 to 8 inches. Seed rice will absorb the maximum amount of water in 18 to 24 hours.

Soaked seed is used instead of dry seed. Soaking starts the germination process before seeding. More important, because it is heavy, the soaked seed sinks into place when it hits the water. Thus the seed does not drift and unseeded areas are not left in the field. Fields remain continuously flooded until drainage for harvest.

Modifications of water-seeding methods broadly adapted to use in the southern rice area have been developed. Slusher (119, 120) extensively discussed the use of aircraft to seed rice in Arkansas.

Adair and Engler (6) described the water-seeding method as used in Arkansas as follows: The land usually is plowed in winter and a seedbed is prepared in the spring by disking two or three times and then harrowing. Frequently, the soil also is tilled to a depth of about 8 inches with a field cultivator to provide aeration and space for applying cool irrigation water that contains dissolved oxygen. Oxygen is essential for early root development. The levees are completed after the soil is worked with the field cultivator and the field is then cultivated between the levees with

a spring-tooth harrow, which leaves shallow furrows and ridges that help to reduce drifting of the seed. The levees may or may not be seeded before final going over with the levee disk. Floodgates are then put in, the field is submerged to a depth of 4 to 6 inches, and the rice is sown from an airplane. Seeding is done as promptly as possible, since poor stands usually are obtained when the water has been on the field longer than about 4 days before seeding.

The airplane operator is guided by flagmen, one at each end of the field, who pace off the distance (about 30 feet) that the plane can sow in one trip across the field. Depending on the length of growing season of the variety being grown and the desires of the operator, the water may be drained from the field after 5 weeks or more to control the rice water weevil, to prevent straighthead, or to provide dry soil for topdressing with fertilizer (6). Occasionally, draining at an earlier date may be necessary. However, unless specific conditions exist that require early draining, it is advisable to drain late because high grain yields have been obtained when flood water was left on fields until shortly before harvest (93).

From tests with water-seeded rice on clay soil in Arkansas, Hall (50) suggested the following:

(1) A disk harrow is effective in preparing the seedbed. On the last trip over, a spring-tooth harrow should follow the disk harrow so that prominent furrows are left in the seedbed to catch the seed and reduce the drift.

(2) The field should be flooded as rapidly as possible with a minimum of 4 to 6 inches of water to control grass. All levees should have a gate or spillway so as to make and maintain a constant level of water and prevent the levees from breaking because of added pressure from heavy rains.

(3) The field should be seeded immediately after the 4- to 6-inch depth of water is obtained. In the test conducted, there was no significant difference in plant stand densities obtained due to seeding in clear or in muddy water that cleared within 24 hours after seeding. Likewise, presoaking the seed showed no significant difference from seeding with dry seed. It was found that seed treated with a fungicide or insecticide, or both, had less tendency to float than did untreated dry seed.

(4) After seeding, the full flood of 4 to 6 inches of water should be maintained for 5 to 6 weeks. Lowering the water depth or draining the field soon after seeding allows grass to become established with the rice, thus defeating the purpose of water seeding. A rate of 135 pounds of seed per acre gives a sufficient number of plants, so that the loss due to wave action is

much less than loss from weeds due to draining the field.

(5) After a period of 6 weeks or more, the field may be drained for midseason nitrogen fertilization.

A few growers in Arkansas pregerminate the seed by soaking it before seeding. In one method the seed is placed in a grain cart such as that used to haul the rice from the combine at harvest-time. The grain cart is filled with water, or water is kept running through the seed for several hours. Then the water is drained and the rice is left in the grain cart overnight. The following day it is augered into the hopper of the plane for seeding. In another method the seed is soaked in bags in a canal for a somewhat longer period, up to 36 hours.

Faulkner (34) compared different practices for water seeding rice in Louisiana. These included (1) pregerminated seed compared with dry seed, (2) cloddy seedbed compared with seedbed that had been smoothed in water, and (3) draining irrigation water 3 to 5 days following seeding compared with leaving a full flood of water and allowing the rice to emerge through the water.

He reported slightly higher grain yields when the seed was soaked to pregerminate it before seeding in the water. He found that a small percentage of the dry seed floated in the water and settled in low spots, whereas the pregerminated seed remained well in place on both the cloddy and smooth seedbeds. However, he pointed out that pregerminating seed requires additional labor and expense and also requires a short interval between germination and seeding.

Faulkner found that the average yield of rice produced from the smooth or the rough seedbeds was approximately the same. However, there were some indications that the working of the soil in water reduced the germination of grass seed and thereby reduced the resulting competition. Also he found that soils that were worked in the water dried more quickly when the water was drained and caused the top one-fourth inch of soil to curl, thereby pulling the young seedlings from their root anchorage. Such conditions would require that the area be flushed.

In this series of experiments, Faulkner found that good stands of rice, along with excellent control of red rice and grasses, could be obtained by leaving a full flood of water on the field until the rice had emerged through the water and was strong enough to stand free from the water. The yield results from 1959 indicated that about 500 pounds more rice per acre was produced where the water was allowed to remain on the field than where it was drained a few days after seeding. Faulkner thought that on the clay soils it might be more difficult to obtain a good stand of rice using the continuous flooding method, but

that additional experiments would be necessary to determine this.

The most common method of land preparation for water seeding in Texas in 1954, according to Reynolds (105), was plowing and disking to kill the vegetation. The land was then left in a rough condition until seeding, at which time the field was irrigated until the water barely covered the land. It was then harrowed to muddy the water. Harrowing to muddy the water before seeding is seldom done early in the season, because dry north winds cause the soil surface to dry rapidly. This drying curls and cracks the soil surface before the seedlings become rooted. The seed usually was soaked in bags in a canal for 24 to 36 hours, removed from the water and allowed to drain, and then sown by airplane on the water. Some farmers drained their fields as soon as possible after sowing, whereas others might delay draining as much as 36 hours. Experiments conducted by Wyche and Cheaney (150) during 1954 at the Rice-Pasture Research and Extension Center showed that under the conditions of the test, soaking the seed, muddying up the water, time of removing the water after seeding, and depth of the water up to 8 inches had no effect on the yield of water-seeded rice. They felt that it would be a good farm practice to leave the surface of the soil slightly rough in order to lessen the drift of seed when water seeding rice.

From observations made on experimental tests and on commercial fields, little if any difference in suitability to water seeding has been noted among varieties. However, in Arkansas where the soils are alkaline, or the water contains excess salts, the medium-grain varieties in general have been damaged less from these adverse conditions when water seeded than have the long-grain varieties, especially the Bluebonnet group. Hall and Thompson (51) pointed out that these problem areas that are colloquially referred to as alkaline have been brought about, on cultivated lands, by the use of well water containing excess salts combined with restricted internal drainage of the soil. Some of these troublesome soils have shown a pH of 7.0 to 7.5, whereas others have been below 7.0. This indicates that pH alone is not a completely reliable indicator of such problem soils.

Nelson (92) conducted an investigation to determine the uniformity of distribution of seeds and fertilizers from airplane distributors and studied the extent to which rate of application, materials distributed, and flight altitude affected uniformity of distribution. He concluded that a fairly good distribution is possible with well-designed equipment if a few precautions are followed. Characteristic deposit patterns should be determined before a new or modified distrib-

utor is first used. From the deposit patterns obtained, optimum flagging intervals can be determined that will allow for an overlap sufficient to maintain a uniform application or seeding rate. For proper overlapping of swaths, a ground crew is necessary. For uniform distribution a flagman should be stationed at each end of the field, and each flagman should be equipped with two long markers connected with a rope or chain length equal to the flagging interval distance. It is necessary that the flagging interval be measured correctly and that the airplane fly directly over the two flags. Recently, many growers have measured these flagging distances or intervals and have marked them with stakes or small flags on wires so that the flagman will not need to measure the distance.

Transplanting Rice

Yields of direct-seeded and transplanted rice were compared in a study conducted by Adair and others (7) in the major United States rice areas during a 3-year period starting in 1937. Three varieties were included in the experiment at three rice experiment stations in the Southern States, and two varieties were included at the California Rice Experiment Station. High yields of transplanted rice often obtained under intense culture in certain countries had led to a more or less common belief that yields of transplanted rice generally are higher than those from direct seeding. Advantages claimed for transplanting were listed and discussed. It was pointed out that high-quality, stiff-strawed varieties already were being grown by machine methods in several countries. During the 3 years of these tests, the average yields of some of the varieties at some locations were significantly higher from direct seeding than from transplanting. None of the varieties at any of the stations produced significantly higher average yields when transplanted than when directly sown. These workers concluded that the principal reasons for transplanting are not to increase yields but to better use land and labor in densely populated countries in which the tillable land area is limited and the labor supply is plentiful.

Irrigating and Draining

Flood irrigation is used for all rice grown in the United States. The soil is submerged in 4 to 8 inches of water most or all of the time from seeding or shortly after, until the grain is nearly ripe. This period may extend from 60 to 90 or more days, depending on method of seeding and variety grown (8, 69). Although the water requirement for rice is high, Jones and others (69) stressed that good surface drainage is as necessary for successful rice culture as is a dependable supply of fresh irrigation water.

Haskell (52) pointed out in 1915 that a plentiful and easily accessible water supply is the first requisite where rice is to be grown. He also emphasized the importance of proper use of available water. He suggested that under certain conditions, it was beneficial to control the flow of fresh water so that it traveled the entire length of each cut. This circulation resulted in more uniform water temperature and helped to control algae (scum) and insects. He also stressed the importance of judicious water management in reducing the effects of certain diseases and other production hazards.

Amount of Water Required

The water requirement of the United States rice crop is comparatively high because the fields are continuously flooded for so much of the growing season. Rice will not produce a profitable crop on stored soil moisture or infrequent rains, as will other cereals (8). When tried in the United States or when used elsewhere, the upland system of rice culture generally results in yields of only 30 to 70 percent of those obtained from flooded rice grown under similar soil and climatic conditions.

Senewiratne and Mikkelsen (114) suggested that differences in growth responses of flooded and unflooded rice may be due to differences in auxin metabolism. They found that plants grown under unflooded conditions had a low catalase activity and a high peroxidase activity, which favored accelerated auxin degradation. They suggested that high manganese levels in plants grown under unflooded conditions affect the indolacetic oxidase mechanism and result in retarded growth and depressed grain yields. Rice grown with ammonium nitrogen (flooded) collected small amounts of manganese, whereas plants grown with nitrate nitrogen (typical of upland rice) contained much more manganese. Clark, Nearpass, and Specht (21), however, concluded that "the better growth of rice in submerged as compared to upland culture in at least some soils is due to greater Mn availability under submerged soil conditions."

Jones and others (69) indicated that from 2.8 to 3.8 acre-feet of water normally was required to produce a rice crop in the Southern States. About one-third of this is supplied by rainfall during the growing season. Robertson (106) reported from early observations that the total seasonal use of water for rice in California normally ranged from 4.3 to 14.8 and averaged 8.2 acre-feet. After a ricefield is flooded, a considerable amount of water is required to maintain an optimum depth in the field. Water is added periodically to compensate for losses due to transpiration by plants, evaporation from the water surface, deep percolation, and spillage. These losses will

vary, depending on amount of plant growth, solar radiation, temperature, wind, relative humidity, soil type, and rate of inflow of water into the field. A rate of flow equal to 1 cubic foot per second (450 gallons per minute) for each 50 acres being irrigated usually is required to maintain water levels on ricefields in California (37).

The apparently lower water requirement for rice in the Southern States as compared to California is related to naturally occurring climatic differences in the evapotranspiration losses from ricefields between the two areas. Whereas the relative humidity during the growing season is quite high in the Southern States, it is comparatively low in California. In California, a vegetation-free water surface will lose from 5 to 6 acre-feet in 12 months, whereas this loss in southern rice areas may be less than half this amount.

Source of Water

It is estimated that 30 to 35 percent of the 1962 rice acreage in the United States was irrigated from wells. Adair and Engler (6) stated that over 40 percent of the 1953 rice acreage received well water. Since that time, however, numerous additional reservoirs have been constructed. Many of these reservoirs were constructed in Arkansas. The reservoirs are filled with runoff water before the ricegrowing season. Other important sources of irrigation water are rivers, bayous, lakes, and drainways.

Adair and Engler (6) discussed the early irrigation of rice and reported that in 1894 the first large irrigation plant was established near Crowley, La. After failures of some pumps, a somewhat larger centrifugal pump was installed in 1896. This pump delivered 5,000 gallons of water per minute, which was enough for the rice acreage planted at that time. During the next few years, many pumping plants were installed on the streams in southwestern Louisiana and southeastern Texas. By 1901 some pumping plants in operation delivered up to 45,000 gallons of water per minute.

Diesel engines came into common use for pumping water after 1919 (6). Convenience, low labor requirements, and reasonable initial and operating costs have since caused a shift to electric power and natural gas power for irrigating rice. In Arkansas in 1955, nearly 50 percent of the 1,800 irrigation installations were powered by electricity. In Louisiana, of a total of 1,061 wells, 450 were powered by diesel engines, 212 by natural gas, 105 by electric motors, and the remainder by other units. In some cases water is pumped or relifted by means of the power take-off unit on tractors.

Historically, most areas in the world where water is pumped from wells have experienced declining water tables. This problem, as related

to Arkansas rice production, was studied by Engler, Thompson, and Kazmann (30). Suggested remedies included the use of deep wells (900 to 1,000 feet) that normally supply more water than shallow wells (100 to 150 feet) and the use of small reservoirs. Engler (29) reported that during a 30-year period, the decline in water level for the Grand Prairie area of Arkansas averaged about three-fourths foot per year, which caused an annual decline in capacity of shallow wells of 20 to 25 gallons per minute. Various methods of replenishing underground water supplies on the farm are discussed by Muckel (87).

Gerlow and Mullins (42) pointed to the value of small, 20- to 40-acre farm reservoirs in conserving surface runoff water to supplement or replace well water for rice irrigation. Another development designed to conserve water (whether from wells or elsewhere) has been the increasing use of underground concrete or lucite irrigation pipelines (laid about 30 inches beneath the soil surface) to transport irrigation water for rice and the accompanying rotational crops. Pipeline irrigation greatly reduces the rodent damage that characterizes open irrigation systems. In addition, it greatly reduces evaporation and seepage losses. Aside from the important aspect of water conservation, it has been calculated that, for each 1,000 feet of open canal replaced with a pipeline, 2.8 acres of land are returned to crop production (3).

Adair and Engler (6) pointed out that pumping from bayous supplies most of the surface water in Louisiana and Texas. According to Anderson and McKie (11), sources of rice irrigation water in Mississippi are shallow wells (90 to 100 feet) and surface water from lakes or streams. Diversion from large streams is the main source of water for rice irrigation in California. It is estimated that less than 5 percent of the California rice acreage is irrigated from wells.

Quality of Water

For successful rice production it is very important that the available water be of suitable quality. Rice irrigation water should be relatively free of dissolved salts that are toxic to rice plants. The characteristics of irrigation water that determine quality include (1) total concentration of soluble salts; (2) relative proportion of sodium to other cations; (3) concentration of boron or other toxic elements; and (4) under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium. Other important factors to consider are the initial salinity of the soil, the effect of internal drainage on the flooded soil, and the total salt content of the soil. Finfrock and others (37) described good-quality rice irrigation water thus:

Specific Electrical Conductivity

(K $\times 10^6$)	less than 750
Boron, parts per million	less than 1
S.A.R. index (tendency to form alkali soil)	less than 10.0

When high sodium water is regularly used each growing season, it may deflocculate the soil, so that stickiness, compactness, and impermeability increase. The deflocculated soil is difficult to cultivate and usually produces low yields.

Pearson (96, 97) described the point of greatest importance as the nature of the soil solution or saturation extract found in the zone of rice roots. If soil saturation extracts have a conductivity index of 4 to 8 millimhos, the yield of Caloro rice may be reduced 50 percent.

Rice is very tolerant of salt during germination, but rice seedlings are very sensitive to salinity during early development (1 to 2 leaves) and are progressively less so at 3 to 6 weeks of age (96, 99). When soils are strongly saline, having an excessively high concentration of sodium, calcium, or potassium, the concentration of salts in the soil solution (including the standing water) may be so great that it will injure or kill the seedling rice (98). Excessive salt concentration results in restriction in downward percolation; therefore, the floodwater is subject to a longer period of evaporation with an ensuing increase in salt concentration. Thus, water having a higher salt concentration enters the soil, and the salt concentration of the soil solution is increased.

Adair and Engler (6) reported that salt water put on dry soil damages a ricefield more than if salt water is used to replenish the water supply in a field that has been watered with fresh water. The reason given was that the salt was more concentrated in the dry soil, and more of it moved into the root zone, where it was taken up by the plants. They indicated that rice grown on clay soils may not be injured as much by salt water as is rice grown on lighter soils, because less water is used and less is lost by seepage.

The rice plant can tolerate higher concentrations of salt in the later stages of growth, although very high concentrations may kill the plants or make them sterile. Some varieties of rice are more tolerant to salt than are others and may make satisfactory yields when the water contains salt concentrations of 75, 150, 200, and 250 grains per gallon in the tillering, jointing, booting, and heading stage, respectively. It is believed that some of the newer varieties would be damaged seriously by such amounts of salt (6).

Irrigation water pumped for rice from shallow wells in Arkansas and other States frequently has a comparatively high sodium con-

tent as compared with water coming from surface streams. Kapp (71) suggested that the source and chemical composition of rice irrigation water should be considered from both the immediate effect on the current crop and the long-range productivity of the soil. In greenhouse and field experiments he found that sodium chloride added to rice soil injured germination and resulted in lowered production of vegetation and grain. The addition of 5,700 parts per million of sodium chloride to the soil only slightly reduced vegetation, but completely prevented grain formation. In field trials, 825 pounds of sodium chloride per acre hindered germination, and 3,300 pounds per acre reduced rice grain yield.

Water from the shallow wells in Arkansas containing 75 parts per million calcium and 22 parts per million magnesium has caused some riceland soils to increase in alkalinity from an original pH of about 5.0 up to as high as 8.0. The change from a highly acid to a highly alkaline reaction is due to the annual addition of about 1,500 pounds per acre of limestone equivalent. The increase in alkalinity has lowered the availability of phosphorus in the soil. If a new source of water low in dissolved minerals is obtained, such changes may be reversed (6). Such water may be obtained from installing a deep well or constructing a reservoir and catching surface runoff water. However, as long as the unfavorable soil condition exists, delaying the initial flood and following a routine of alternate draining and reflooding at 4- or 5-day intervals until the plants are about 6 weeks old have given fairly satisfactory relief in Arkansas.

When the rainfall is below normal in the Gulf Coast area of Louisiana and Texas, the water level in the streams that supply irrigation water often is so low that brackish water encroaches from the Gulf. The concentration of chloride salts may become so high that the yield and quality of rice is reduced or the crop is ruined. Adair and Engler (6) pointed out that several workers had shown that water containing more than 35 grains of salt per gallon (600 parts per million) should not be used to irrigate young rice if the soil is dry and if the water is to remain on the field. Rice watered continuously with water containing 35 and 75 grains of salt per gallon was reduced in yield about 25 and 70 percent, respectively, and the rice was of lower quality than when water containing only 25 grains per gallon was used.

Water quality in California ricefields was studied by Stromberg and Yamada (135). They found that water that contained a high total of soluble salts killed rice plants. However, when a field showing initial symptoms of dying was immediately flushed out with quantities of wa-

ter low in total salts, the plants soon recovered. Water low in total salts was used for the remainder of the season, and a normal crop of grain was produced.

In California, rice culture has proved useful in reclaiming saline soils, provided the fields to be reclaimed are first engineered to drain well. Mackie (77) reported that one rice crop grown in Imperial clay near Imperial, Calif., reduced the saline content 72 percent to a depth of 6 feet. In his experiments he found the usual reduction in saline content from the first rice crop to be one-third to two-thirds. Overstreet and Schulz (95), in a series of San Joaquin Valley tests, concluded that rice culture serves as an efficient means of reclaiming nonsaline soil containing 15 percent or more of exchangeable sodium.

Water Temperature and Oxygen Content

The temperature of water with which rice is irrigated has a profound effect on the plants. Adair and Engler (6) reported that the temperature of rice irrigation water pumped from wells and from streams frequently is 65° F. or lower. When such cool water goes directly into the field, the rice growing near the water inlet usually is retarded and may ripen as much as 7 to 10 days later than the rest of the field. Raney, Hagan, and Finrock (103) showed that with the building of high dams on the major California streams, the temperature of water available for rice irrigation from surface streams had dropped to 51° or less.

The temperature of the irrigation water should be not less than 70° F. nor more than 85° for best results. Raney (102) showed that the critical seasonal threshold of water temperature for normal growth of Caloro rice was near 69°. When the mean temperature was 5° lower, maturity was delayed 30 days beyond the normal 160 days. Rice yield was highest when the mean water temperature was 80°. At water temperatures above 85°, yield was reduced and root development was poor, probably because of low oxygen content of the water.

Chapman and Peterson (20) studied underwater rice seedling establishment in relation to temperature and dissolved oxygen. Under laboratory pot culture they found water temperatures in the range of 77° to 84° F. most favorable for the effective establishment of rice in static culture. Emergence of the shoot from the water was most rapid at 84°, but the development of the root system and the penetration of the soil were favored by temperatures as low as 68°. Exposure to a water temperature of 104° for 12 hours or more was lethal to pregerminated Caloro rice seed. They concluded that it seemed unlikely that dissolved oxygen deficiency would



FIGURE 34.—Headgate that controls flow of water from canal into ricefield.

be a limiting factor in seedling establishment in the field even at 95° , if currently recommended seeding rates were used and the water had an initial oxygen content of at least 5 to 6 parts per million.

Ehrler and Bernstein (28) reported that at a constant root temperature of 64.4° F., Caloro shoot growth was twice that at 86° and root growth was one and a half times as great; however, grain yield was only three-fourths as much at the lower root temperature. No significant interaction was found between root temperature and cationic concentration or cationic rates.

Seeds germinate slowly when the temperature is less than 70° F. Water now available for rice irrigation in some areas, including northern California, may be colder than this, ranging down to 51° or less. Such cold water will retard and lower the germination of rice sown in the water and will retard the development of plants so that the stand may be thin and crop maturity will be delayed near the inlet to the field. According to Raney, Hagan, and Finfrock (103), field studies over a 3-year period showed that plant-free

water-warming basins, 6 to 12 inches deep, equal in size to 2 percent of the area to be served, successfully and economically raised the mean water temperature of 60° to 70° .

Water Control Methods

Methods of transporting and controlling irrigation water for rice production have evolved over the years. They vary in different rice-producing areas but tend to follow a general pattern.

In most cases water is conveyed from the pumps, streams, or reservoirs in canals from which it is diverted into laterals, into field ditches, and finally into the field checks or paddies. Water is usually delivered to the highest point in the field by canals or pumps. It passes into successively lower paddies through metal levee gates or levee control boxes or openings in the levees. These gates or boxes provide permanent control of maximum water depth in each paddy.

Water that overflows or is drained from the

lowest paddy may be caught in drainage ditches or canals and recirculated or moved into other canals or drainage ditches. Some fields have a canal along one side so that each paddy can be watered separately from this canal. Finfrock and others (37) described in detail the rice irrigation control structures used in California.

CANAL GATES.—Gates in the irrigation canals of the California ricegrowing areas are simple structures of wood or concrete (fig. 34). In the vertical fixed portion of the structure, slots are provided so that short planks (flash boards) can be inserted or removed as desired to raise or lower the water level at the diversion point into the field. Inlet structures to the field may consist of similar slotted wooden structures or screw-type metal gates. The latter commonly are used in the southern rice area.

LEVEE BOXES OR GATES.—Water is controlled within the field with boxes or gates set at convenient locations in the levees. In the southern

rice area, metal levee gates with adjustable panels are in common use in some localities (fig. 35). Variations that may be used include single planks or boards or metal panels which are forced into the soil across a narrow cut through a levee to keep the water at the desired level. In California, the levees are usually considerably larger than those in the Southern States. The wooden or metal boxes are placed along the more accessible side of the field. Flash boards of various widths are added or removed to regulate the water to the desired depth. Boxes must be properly constructed and installed so they will not be washed out (fig. 36).

DEPTH STAKES.—To gage the water level in a paddy or check, a depth stake is driven into the soil within a suitable distance of the levee box or gate. The stake is set so that the bottom of an 8-inch red band is at the average elevation of the ground surface in the paddy. If a 5-inch flood is desired, then 3 inches of the red band is



FIGURE 35.—A ricefield in Arkansas that is irrigated and ready to be seeded, showing the gates used to regulate the flow of water from one check to another. (Photo by Copeland.)



FIGURE 36.—Levee box used in California to regulate flow of water from one check to another in ricefield.

left showing. The stake is painted white at the top, so that if an 8-inch flood is desired, only the white band is left exposed.

Construction of access roads around ricefields helps to (1) cut production costs because equipment can be moved more easily into the field; (2) control water better and more economically; and (3) control mosquitoes by reducing seepage problems, by making it easier to control weeds where mosquitoes breed, and by enabling mosquito abatement employees to reach troublesome spots.

PROTECTION OF IRRIGATION SYSTEM.—Once they are engineered and installed, riceland irrigation and drainage structures are subject to damage from use, the elements, and insect or animal pests; but countermeasures can be employed. In large, flat paddies or checks, wind levees may be constructed between the normal-interval levees to decrease wave action. Their judicious placement in areas subject to strong winds may be very beneficial. So-called alkali levees built from soil high in sodium and other salts frequently are subject to washouts or breaks when fields are flooded. Heavy applications of gypsum on such areas before pulling the levees help to stabilize the soil and greatly reduce the chances of breaks. Plastic sheeting or various types of laminated paper also can be used to cover weak areas in levees. Soil is plowed or shoveled onto the edges of the material to prevent its floating when the field is flooded. Certain pests, such as muskrats, field mice, Norway rats, crayfish, and large insects, often inhabit canal and drainage ditchbanks, as well as contour levees. Their burrowings may result in levee or bank leaks or breaks and heavy water loss. Major structures, such as weirs, can be protected to some extent by

trapping or poisoning the pests. In California fields where the large levees sometimes are inhabited by crayfish and muskrats, the problem has been solved by using sheep to graze the vegetation from the levees.

Water Management

The application and management of water is a key operation in rice farming (89). The principal functions of water cover are to control weeds, to condition the soil and provide a favorable environment for rice growth, and, especially in California, to serve as a temperature regulator by minimizing the effect of the large variations between daytime and nighttime air temperatures.

Systems of water management for rice production vary widely, depending on method of seeding, soil type, climate, crop rotation, diseases, and insects. A very important aspect of water management is good drainage. This includes drainage of winter rainwater as well as periodic drainage during the growing season. In years when riceland is used for rotational crops, the crops may be drowned if drainage is poor. Seedbed preparation and fall harvest can be expedited by a good drainage system. Drainways around and through the field that connect with main drainage ditches leading to natural drainage channels are essential. These ditches should be large enough and deep enough to allow the removal of large quantities of water quickly. When it is necessary to preirrigate or to flush irrigate to bring about emergence of rice, good drainage plays a key role in getting a good stand quickly by expediting fieldwork and reducing seed rot losses (8, 69). Good drainage of ricefields and adjacent areas and ditches also is of prime importance in eliminating mosquito-breeding areas.

Essentially there are two broad systems of water management, depending on the method of seeding. The first broad system of water management revolves around drilling or broadcast seeding on "dry" ground. Where necessary, seeding is followed by flushing to bring about uniform emergence, and the first flood is applied later. This system is often used in the southern rice area. With the second broad system of water management, fields are flooded just before aerial seeding and usually remain flooded until they are drained for harvest. This system is used in California, and with modification also is used in the southern rice area. In the southern rice area (especially in Texas), where rice is water seeded on heavy soils, some growers drain as soon as possible after seeding; others may delay draining for 36 hours. After stand establishment, irrigation practices are essentially the same as for drilled rice (8).

Unless rice is water seeded and the flood is maintained, a flood is applied about as soon as the

crop is old enough to withstand submergence. As a means of weedy grass control, ricefields on the lighter soils in Arkansas often are flooded as soon as the rice has emerged. If the fields are free of weedy grasses or if these grasses have been chemically controlled, the land may not be submerged until the rice seedlings reach a height of 4 to 6 inches. Jones and others (69) indicated that at this stage the land is submerged to a depth of 2 to 4 inches. As the plants grow taller, the depth of water gradually is increased until it reaches 4 to 6 inches. During the rest of the growing season or until the land is drained before harvesting (except for special reasons), the water may be held on the land at a depth of about 5 inches. To maintain this constant depth, additional water should be applied to replace that lost by evaporation, transpiration, and seepage.

Reasons for draining ricefields during the growing season and allowing the soil to dry include (1) control of algae (scum); (2) control of rice water weevil; (3) prevention of straighthead (blight); (4) control of aquatic weeds such as mudplantain (ducksalad); and (5) application of nitrogen fertilizer. On saline or alkaline soils it may be necessary to drain fields several times early in the growth of the rice to allow the plants to become well established.

ARKANSAS.—Adair, Miller, and Beachell (8) reported that water management is similar in Arkansas and Louisiana. Depending on growing conditions and grass control methods being used, the first flood may be applied as the rice is emerging, or it may be delayed for 2 or 3 weeks. The majority of ricegrowers in Arkansas drain their fields about midway in the growth of the rice and allow the soil to dry before applying nitrogen fertilizer. The fields are then reflooded, and observations indicate that nitrogen is taken to the rice roots as the water soaks into the soil. This results in more efficient use of the fertilizer.

Hall (50) described the water-seeding method used by some Arkansas growers. Seed is broadcast by plane into fields immediately after the application of 4 to 6 inches of water. The flood may be held for about 6 weeks before draining for the midseason application of nitrogen fertilizer. Other growers may drain their fields soon after the seed is sprouted and reflood after a few days. If fields are left drained for several days, heavy stands of grass weeds may become established. When rice is water seeded on heavy clay soils, this early draining is a common practice. The fields then are reflooded after about 3 days and the flood is maintained until midseason.

In a series of greenhouse experiments, Hall (49) found that unless rice plants were fertilized, the practice of draining and drying the soil and then reflooding did not increase grain production on soil low in organic matter.

LOUISIANA.—Jenkins and Jones (62) found that in date-of-submergence experiments in Louisiana, the highest average yields were obtained on land submerged 20 days after the seedlings had emerged. In a discontinuous and continuous submergence experiment, early continuous submergence (10 days after seedling emergence) of the land gave higher average yields than did intermittent drying of the land followed by continuous submergence.

In Louisiana, water seeding is not common; but where it is practiced, the water is drained when the rice seedlings are one-half inch long, according to Wasson and Walker (145). It then is allowed to grow until flooding is needed. Drilled rice may be flushed if necessary for uniform germination. Normally the rice is not flooded until it is 6 to 8 inches tall, and then only to a depth of 4½ inches. Fields are drained as necessary for topdressing with fertilizer and for pest control.

MISSISSIPPI.—Mullins (89) stated that rice in the delta area of Mississippi is kept flooded for 90 to 120 days during the growing season, depending on variety and seeding date. The first flood is applied as early as possible after the rice seed germinates and a stand is established. This may be about 2 weeks after seeding or, if germination is slow, possibly 3 weeks after seeding. Application of the first flood requires close attention to avoid breakage of levees and to stabilize the water at the desired level. If the levees are accurately located and well constructed, relatively little time is required to apply the first water; otherwise, labor requirements may be much higher. Mullins reported that most fields were drained after 3 to 4 weeks under flood and the soil was allowed to dry for several days. This permitted the roots of the rice plant to become more firmly established and also stimulated additional tillering. He suggested that if grass was well under control at this time, fertilizer could then be applied.

TEXAS.—Reynolds (105) stated that where rice is seeded with a grain drill on heavy soils, the fields usually are flushed (irrigated) for germination if water is available and if the soil has not been saturated by rain. Flushing usually is practiced in areas irrigated from canals, since the fields can be covered rapidly. Sandy soils and soils irrigated from wells usually are not flushed. After fields are flooded, irrigation water may be drained off once or twice during the growing season to permit fertilization and to control water weeds and insects. The time and number of drainings may vary, depending on the length of maturity of the variety, the presence of weeds and insects, and the supply of irrigation water. Where there is a shortage of water for reflooding, the fields usually are not drained. If irrigation is required to germinate the seed, the field is

promptly drained after this flushing. Where rice is seeded with an endgate seeder, the land is then harrowed and irrigated and the irrigation water is drained off shortly thereafter. It has been found from tests and general observations that satisfactory rice stands are not obtained if seeds are covered by both soil and water, so that draining water from fields where the seed is covered with soil is extremely important.

Morrison (85) found little difference in the rice yields at Beaumont when the total amount of water used ranged from 46 to 73 inches. He concluded that the use of 45 to 50 inches of water would be just as satisfactory as the use of larger amounts. These results generally agree with those reported by Jones and others (69). It was further concluded (85) that the depth of water does not seem to be of much importance where weeds are not a problem. Draining ricefields once during the growing season increased the yield of rice considerably.

Evatt (31) reported that preliminary tests conducted at the Rice-Pasture Research and Extension Center in 1956 and 1957 showed significantly reduced rough rice yields of the Century Patna 231 variety with use of deep water (10 to 12 inches), compared with use of average depths of water of from 4 to 6 inches from late tillering to maturity. He found that the temperature variation was 2 to 4° F. greater under the shallow water than under the deep water. Yields from superimposed fertilizer factorials showed no significant fertilizer-water depth interactions in 1956. However, in 1957 yields were less from both nitrogen and phosphorus treatments under the deeper water.

CALIFORNIA.—In California where japonica-derived varieties predominate, ricefields normally are rapidly flooded to a depth of 6 to 8 inches just before seeding. Then they are seeded with pre-soaked seed immediately after flooding to enable the developing young rice plants to compete efficiently with soil organisms for available oxygen and with weeds for space and nutrients (36). The water is maintained at that depth until it is drained for harvest. Water may be lowered to about a 3-inch depth for weed control and at stand-establishment time during cool weather. If the soil in the field contains excessive amounts of salts, the water may become sufficiently saline as to be toxic to the rice seedlings. In such cases the water may be drained from the field and fresh water applied immediately. The continuous flood system commonly used in California was developed to control weeds, principally watergrass, and to fit the fertilizer requirements of rice (38, 83).

Draining for Harvest

Draining at the proper time before harvest is necessary to dry the soil enough to support harvesting equipment. It is equally important to

hold the water on the land long enough to permit the rice to reach proper maturity.

The time to drain depends on the type of soil, drainage facilities, and seasonal weather conditions. Some soils dry and crust quickly after drainage; others dry slowly. Less time is required to dry the soil early in the season when temperatures are higher and the days are longer than is required later in the fall. Growers soon familiarize themselves with the drying time of their soil, so that they can judge when to drain the fields to permit harvesting and yet not let the crop suffer for lack of soil moisture.

Usually the land may be drained when the rice is fully headed and the heads are turned down and are ripening in the upper parts. This stage ordinarily will be about 2 to 3 weeks before the crop is ready to cut. The date when the rice will be ready for harvest can be estimated by observing the date of first heading (when approximately one-tenth of the rice heads have emerged). Rice in the South normally requires 35 to 45 days from first heading to maturity. In California, crops of average yield will be ready for harvest about 45 days from the first heading. Heavy crops with yields of 5,000 pounds or more per acre may require as many as 55 days from first heading to maturity.

Water intake should be discontinued a few days before final drainage. The water already on the field will then recede slowly. This lessens lodging and does not overtax the drainage system with excessive water. In the South the field may be drained by removing the levee gate panels or by "cutting" the comparatively small levees with hand shovels. Levee gates sometimes are upended or may be removed from the fields before harvest. Dynamite is used quite extensively in California for opening levees to permit draining of ricefields before harvest. The levees are blown where they cross the drains that are installed within the fields. The dynamiting, which requires experienced powdermen, is started at the lower end of the field.

Harvesting, Drying, and Storing

Harvesting

Most rice grown in the United States now is directly harvested with self-propelled combines. It is then dried artificially before storing or milling. A small amount of seed rice is cut, swathed, and threshed from the windrow when the seed has dried down to 12 percent moisture or less. Direct combining and artificial drying is the most efficient and economical way of harvesting rice. Careful adjustment of the combine and proper drying methods result in grain having highest milling quality and commercial value.

Before adoption of direct combining, the United States rice industry used three other harvest methods, according to Smith (124). These, in order, were (1) harvesting by hand with a sickle or cradle, and then stationary threshing; (2) cutting with team-drawn or ultimately with tractor-drawn grain binders, handshocking the bundles, and then engine-powered stationary threshing; and (3) cutting with a tractor-drawn header or swather, followed by threshing from the windrow (when the grain was dry) with a pickup combine.

Direct combining was first tested in Arkansas and Texas in 1929 (126). According to Bainer (13), approximately 3,000 acres of rice were harvested by combines in 1929 in California, and nearly 35,000 acres in 1931. The combined harvester-thresher had been developed primarily for wheat, and the first models were not well suited to ricefield conditions. Low wet spots, weed patches, and high, narrow levees made combine harvesting difficult.

At the same time that combine harvesting was first being tried, tests were being conducted on artificial drying of rice (126). Even with the problems encountered in combining and artificial drying of rice, numerous advantages were cited. These included: (1) In one operation rice is removed from fields with no danger of weather damage; (2) very little loss of rice is sustained through shattering; (3) rice of high milling quality can be obtained regardless of weather conditions at harvest; and (4) all the rice can be thoroughly and uniformly dried, making it safe for storage either in bulk or in sacks. Also, it was pointed out that artificially dried rice usually is more uniform in quality because of the thorough mixing during the drying operations.

Additional advantages of the combine method over the binder, as pointed out by Slusher and Mullins (121) were (1) the elimination, to a large extent, of the need for outside labor for harvest; (2) less chance for loss from destructive wildlife, principally blackbirds and ducks; (3) possibility of salvaging a much higher percentage of crop in case of storm or wind damage; and (4) reportedly less field loss. These authors found that hand labor used in harvesting was reduced from slightly more than 11 hours per acre with the binder to from 2.4 to 3.6 hours with the combine method, depending on the size of the machine used. They reported that 400 acres of rice approaches the maximum seasonal acreage that a grower can safely plan on harvesting with one 12-foot self-propelled combine. Slusher (120) indicated that the usual crew for the self-propelled combine method consisted of one man on the combine, one man with a tractor and grain cart to haul grain from the combine to the truck, and two men and trucks to haul grain to the drier

or elevator. One such crew usually could harvest about 16 acres of rice per 10-hour day.

Mullins (89) emphasized that the time required and the cost of harvesting depend largely on the weather at harvesttime. Heavy rains and wind often cause excessive lodging and create unfavorable surface conditions for operating combines and other equipment. Severely lodged rice may be harvested with combines that have adjustable pickup reels. When this is necessary, the combine must be operated at a much lower speed across a field, which greatly increases the time required for harvesting.

In a study of a large number of samples that included the effect of method of harvest on rice mill yield and grade, it was concluded that there was little difference between the combine method and the binder-thresher method of harvest as it related to the market value of the rice obtained.

Most rice now is handled in bulk (122), although some, especially that being saved for seed, still is sack dried. The conversion from sacking rice in the field to bulk handling was accentuated by increasing costs and scarcity of sacks and hand labor.

Today the self-propelled rice combine harvesters are equipped with relatively large bins or hoppers for collecting the threshed grain (fig. 37, *A*). The hoppers then are emptied by mechanically augering the rice into self-propelled "bank-outs" or tractor-drawn carts that take the rice to waiting field-side trucks (fig. 37, *B*). Rice then is hauled to driers (figs. 37, *C* and 37, *D*) or to aeration bins (fig. 38) where it is unloaded by use of grain augers or other bulk-handling methods.

Hurst and Humphries (61) discussed harvesting of rice with combines and pointed out that care should be taken not to crowd the feed. Because rice straw is heavy and green at harvest, the ground speed of the machine should be slow enough to avoid clogging. Since the rice kernel is very susceptible to cracking, the cylinder should be run at a slower speed than for other cereal crops. Allowing a small percentage of kernels to crack may be necessary to thresh out a maximum yield.

Special self-propelled rice combines used in California are equipped with crawler tracks that enable the machine to cross wet spots, small ditches, and low levees. In rainy seasons, wide wooden mud cleats are bolted on to the tracks to increase the support for the harvester. Self-propelled combines used in the ricefields in the South usually are equipped with large tires with mud lugs so that they can be operated over the sloping levees.

In recent years, specially designed rice combines have been built by the major farm machinery manufacturers in the United States and are being used in the ricefields of the South and

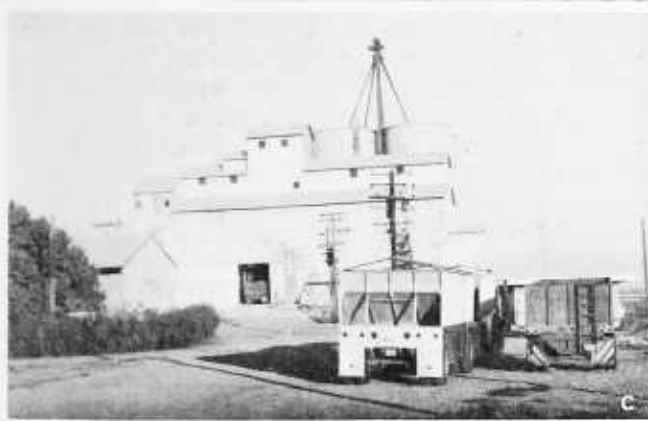


FIGURE 37.—A, Cutting and threshing rice with a combine harvester that is loading the rice into a "bank-out" or grain cart; B, transferring the rice from the "bank-out" into a truck in a road at field side; C, trucks loaded with rice waiting to unload at a farm drier; D, unloading the rice at the drier.

the West. These high-powered machines commonly have 12- to 16-foot headers and can be operated under extremely muddy conditions. They can be adjusted to do a thorough job of threshing with a minimum of shelling and cracking of the grain. Most combines now are equipped with straw choppers, which cut up the rice straw as it leaves the combine, and a distributor, which spreads the straw particles uniformly over the stubble to facilitate plowing under.

The effect of combine adjustment on harvest losses of rice was studied by McNeal (79). He found that there were four types of combine losses—cutter bar, cylinder, rack, and shoe. To obtain maximum grain yields, it was necessary for the cylinder bars and the concave to be in good condition and for the concaves and other parts of the combine to be properly adjusted. He concluded that combine ground speed should be reduced to one-half mile per hour when the rice is badly lodged. He indicated that the operator



FIGURE 38.—Bin drying combined rice on the farm.

is the most important factor in preventing high combine losses. The height at which the rice was cut was very important, since the proper amount of straw served as a cushion to the grain in the threshing process, and resulted in a lower cylinder loss and less hulling and breakage.

Curley and Goss (22) found that combine losses also may be due to overloading or improper machine adjustment or a combination of the two. Overloading as a result of excessive ground speed usually is the major cause for excessive loss in all sizes of combines.

Their tests in rice indicated that total combine loss including reel shattering should be less than 5 percent of the gross yield if the machine is properly adjusted and operated. Thus, the loss from a 6,000 pound per acre yield should not exceed 300 pounds. A high loss of unthreshed grain usually resulted from improper cylinder or concave adjustments, or from both. High loss of threshed seed came from poor separation in the straw walkers and cleaning shoe. They found that under California conditions reel shattering losses normally were insignificant in rice as compared with other small grains.

Curley and Goss suggest that several loss checks should be made on a machine in a given area to determine the effect of adjustment or change in ground speed. Detailed recommendations for machine and procedural adjustments for harvesting rice under California conditions also are listed by these workers.

MOISTURE CONTENT OF GRAIN AT HARVEST.—Smith and others (127) pointed out that rice must be of high milling quality to command a premium price, and that for this high quality and for maximum grain yields, rice must be cut at the proper stage of maturity. If the crop is harvested when immature, field yields usually are reduced and the breakage in combining and milling is excessive because of the light, chalky kernels. If the crop is left in the field until over-

ripe, the kernels may check. This causes severe breakage during combining and milling and a reduction in the yield of head rice (whole kernels). Smith and others emphasized that when rice has reached the proper stage, harvesting should proceed rapidly, since loss of moisture in standing rice may be very rapid. In rice harvested at the proper stage, the grains were fully mature in the upper portions of the panicle and in the hard-dough stage at the base. Few, if any, chalky kernels were found in rice harvested at this stage of maturity. When such rice was properly dried, germination was satisfactory for seed purposes.

Bainer (13), Davis (25), Kester (72), McNeal (80), and Smith and others (125, 126, 127) have reported results of research relating stage of maturity (moisture content) of the grain to proper harvesttime. Although their findings varied, they were in general agreement that maximum yield of head rice was obtained when rice was harvested at a moisture content of about 18 to 24 percent and then immediately dried to between 13 and 14 percent.

Varieties differ in the range of harvesttime moisture content at which they yield the best quality milled rice. McNeal (80) reported that a range in moisture content of 16 to 22 percent provided the highest yield of head rice for Rex-ark and that a range of 17 to 23 percent provided the highest yield for Zenith. Davis (25) reported that the best range for Caloro was 20 to 25 percent, and Kester (72) and Kester and Pence (73) reported that the best range for Calrose was 22 to 27 percent. Their work showed that for every 1-percent reduction in kernel moisture while the unharvested grain was left in the field, the decline in head rice yield from the maximum was 1.4 percent for Caloro, 0.9 percent for Calrose, and 1.0 percent for Colusa.

Most ricegrowers determine the moisture content of hand-harvested samples of their rice before beginning harvest. Determinations usually are made with electrically operated moisture meters, which they own or which are available at the commercial driers.

Although kernel moisture content at harvesttime strongly influences rice quality and milling characters, environmental factors that affect the plant physiologically during the growing season also influence quality. Halick (48) has shown that a variety that ripened under lower temperatures (81° to 84° F.) produced higher head rice milling yields than did rice that ripened earlier in the season under higher temperatures (90° to 94°). Stansel, Halick, and Kramer (134) found that high temperatures (90° day and 80° night) increased chalkiness in all four varieties studied (Century Patna 231, Bluebonnet 50, Toro, and a glutinous variety). California rice quality

studies (73) showed that certain crop fertilization practices could result in declines in kernel characters such as weight, water uptake, hot-paste viscosity, and whiteness. Thus, when harvesting for maximum quality, many factors must be considered; but certainly moisture content of grain at harvesttime is among the most important.

PREHARVEST CHEMICAL DRYING.—Results from experiments with the preharvest application of chemical desiccants to speed the drying of rice in the field have been reported by Addicott and Lynch (9), Hinkle (57, 58, 59), Smith, Hinkle, and Williams (123), Tullis (139), and Williams (147). All materials were applied as sprays when the rice contained from 20 to 27 percent moisture. Materials tested at varying concentrations included (1) sodium chlorate-borate mixtures; (2) magnesium chlorate; (3) disodium 3,6-endoxohexahydrophthalate (alone and with ammonium sulfate); (4) sodium monochloroacetate; (5) S, S, S-tributyl phosphorotrithioate; (6) sodium pentachlorophenate; (7) di-nitro-O-sec-butylphenal compounds (alone and in combination with aromatic oils); and (8) aromatic oils alone. Some of the chemicals studied by these investigators hastened the drying of rice in the field. However, none were entirely satisfactory because the milling quality was reduced, the kernels were discolored, or the chemical imparted an off-flavor to the rice.

Desiccants are used occasionally to hasten the drying of seed rice. However, no grower should use a desiccating chemical on his maturing rice crop until he has checked with his local agricultural authorities to determine its legal status with reference to chemical residue tolerances. Laws are strictly enforced in this regard, and an entire crop could be impounded if it exceeds the legally established chemical residue tolerances.

Drying and Storing

For the proper drying of rice, moisture must be removed from inside the kernel (23). If rice is dried too rapidly or if the temperature of the drying air is too high, quality is seriously impaired. To prevent internal checking or breaking of the kernels from drying too rapidly, drying usually is done in three to five stages. In each stage the rice passes through the drier and then is tempered in a bin, so that the kernel moisture will equilibrate.

Bainer (13) published one of the earliest accounts of artificial drying of combine-harvested rice. He concluded that rice could be dried successfully by artificial means but that the temperatures in the drier should not exceed 100° F.

Smith and others (126) reported on early research on artificial drying of rice in Arkansas and Texas. They concluded that a drying-air temperature of 120° F. could be used without injur-

ing the rice if the moisture content was reduced only about 2 percent at each drying operation and the rice was allowed to remain in storage 12 to 24 hours between drying periods. However, when necessary to dry a given lot of rice in one operation, the drying-air temperature should not exceed 110°.

From experiments conducted with combined rice in 1944, 1945, and 1946, McNeal (78) concluded that in most cases the head rice yield was increased and the total drying time was decreased as the number of dryings was increased from one to four at temperatures ranging from 100° to 150° F.; and the tempering period between dryings was important, since it gave the moisture in the grain an opportunity to equalize and thereby reduced drying time. On the basis of more recent experiments, McNeal (81) concluded that the most desirable drying combination appeared to be four dryings at 120°.

In 1953, Aldred (10) summarized research on drying and storing rough rice in the Southern States. This summary covered work conducted by the Agricultural Experiment Stations in Arkansas, Louisiana, and Texas, and by the U.S. Department of Agriculture. This author gives information on volume of air used in column-type and bin-type driers; number of stages to use in drying rice; temperature of the air for drying; depth of rice when dried in bins; length of time rice can be held before drying; and the use of fumigants to protect rice from storage insects.

A comprehensive review of research in the United States on conditioning and storing rough and milled rice through 1958 (23) was published in 1959. This review cited 74 specific references and included participation by 36 contributors.

TYPES OF DRIERS.—Driers can be classified by type as (1) continuous flow, including mixing and nonmixing; and (2) batch, including bins and potholes. Driers can also be classified as multi-pass and uni-pass. Multi-pass is a continuous-flow system; uni-pass is a batch system.

Wasserman and others (142) reported that mixing-type driers are of many designs. Two of the most popular mixing-type driers are the baffle design and the Louisiana State University (LSU) design (1). In the baffle design, rice is conducted downward in a zigzag path by means of baffles, while heated air is forced through the grain. In the LSU design of the baffle drier, layers of inverted-V-shaped air channels are installed in a bin with alternating air-inlet and air-exhaust channels. Each layer is offset, so that the tops of the inverted V's split the streams of grain as it flows down between the channels. Drying air passes from the air-inlet channels through the rice and out the air-exhaust channels (142).

Wasserman and others (142) stated that the

nonmixing columnar type drier is the simplest and most commonly used. In this drier, rice descends between two parallel screens set 4 to 6 inches apart while heated air is blown through the screens and intervening rice. No appreciable mixing occurs, and the effect is similar to drying in a static bed with a depth equal to the distance between the screens.

According to Morrison, Davis, and Sorenson (86), bin drying refers to drying grain in storage bins usually at depths of 6 to 8 feet. Normally the grain is dried in the same bin in which it is stored, which makes the method particularly suited to on-farm installations. In contrast, aeration is defined as the procedure used to cool and ventilate grain during storage to maintain quality. This is accomplished by turning the grain at frequent intervals, by transferring the grain from one bin to another, or by circulating air through the stored grain. Although drying may be accomplished with unheated (normal atmospheric) air under favorable conditions, a source of supplemental heat should be available during periods of high humidity.

Bin drying, consisting of drying with unheated air but supplemented with artificial heat, is used in on-farm installations, especially for seed rice. Supplemental heat refers to heat added to atmospheric air for limited temperature rise, usually less than 20° F., to accomplish drying within a maximum permissible time to prevent spoilage. Barr and others (15), Henderson (53, 54, 55), Hildreth and Sorenson (56), Sorenson (129, 130), and Sorenson and Davis (131), all discuss the requirements for successful bin drying and its limitations.

Sorenson, Davis, and Hollingsworth (132) pointed out that some rice for seed is dried in pot-hole-type sack driers.

McNeal (81) describes two distinct procedures in use for commercial rice drying. These are the multi-pass system and the uni-pass system. In the multi-pass driers, air heated to approximately 120° F. is passed through a continuously moving column of rice in three or more passes. During the first pass a predetermined amount of moisture is removed; then the rice is stored for about 24 hours to allow the moisture to equilibrate throughout the individual kernels. As many additional passes are used as are necessary to reduce the moisture content of the rice to a safe storage level.

In uni-pass driers, air heated to 110° F. or higher is passed continuously through the column of rice in one operation until the moisture content of the grain is reduced to safe storage level. This system employs a pack 10 inches thick, and the direction of the heated drying air is reversed at regular intervals and the drying is accomplished in one pass.

SOURCES OF HEAT FOR DRIERS.—The amount of heat required for warming the air used by a rice drier depends on the initial temperature and moisture content of the air. The approximate quantity of heat required to raise the temperature of each 1,000 cubic feet of air and its moisture 1° F. is about 18.1 B.t.u.'s. To take care of initial air temperature, heat losses, and periods of above average humidity, results of experiments at Crowley, La., indicated that the heat source should provide 2 B.t.u.'s per minute for each cubic foot of air used. The most satisfactory source of heat was found to be natural or butane gas. It was pointed out that gas burners are relatively inexpensive and are easily regulated to maintain a desired air temperature. Also, since a clean flame is produced, the burner can be directed toward the inlet to the blower and the products of combustion allowed to pass through the drier (1).

DRYING RATE AND TEMPERATURE.—Unlike most cereals, rice is consumed primarily as unbroken kernels, so that the market value for whole kernels is much greater than that for broken kernels. Therefore, to avoid breaking the rice kernels, much more care is required in drying rice than in drying other cereals. The drying rate of rice depends on the rate of migration of moisture from the inside to the outside of the kernel. As the rice kernel is dried, the outer portion shrinks, setting up stresses and strains. When too much moisture is removed too rapidly, checking or shattering of the kernel results. To reduce this effect, rice is dried with air at 100° to 130° F. in two or more stages or passes through the drier. Between passes through the drier, the grain is held in a bin to allow the moisture to equilibrate throughout the individual kernels. This tempering relieves stresses and strains and facilitates drying in the next pass. Laboratory-scale studies with California-grown rice showed how drying-air temperature and number of passes through the drier affected head rice yield and total drying time. The relation of these factors has been represented on a single diagram to serve as an operating guide in the drying of rice (142).

EFFECTS OF HIGH TEMPERATURES ON SEED VIABILITY.—McFarlane, Hogan, and McLemore (76) studied the effects of heat treatment on the viability of rice. They also surveyed the literature involving rice and other grains. Germination tests confirmed that the effects of high temperatures on the viability of naturally moist rough rice were much the same as for other kinds of seed similarly treated. General observations included the following: (1) For a given sample of rice, the zone of heat damage (beginning of heat damage to loss of viability) is narrow; (2) the resistance of rough rice to impairment of its viability by heat varies inversely as its moisture content; and (3) when viability of rice is dam-

aged by heat, loss in germination vigor is apparent before loss in germination capacity.

In artificial drying experiments with seed rice, good results were obtained by continually rotating the seed from bin to drier to another bin until dry. An inlet air temperature of 120° F. and a 20-minute drying period were used. This method reduced drier capacity somewhat but eliminated the possibility of mold or fungus attacking the germ of warm, damp rice between drying periods (1). McNeal (78) showed that germination percentages were reduced when rice was dried at air temperatures above 130°.

IMPROVING EFFICIENCY OF COMMERCIAL DRIERS.—Recent studies have shown how commercial drier capacity could be increased by about 50 percent and head rice yield by 2.5 percent without significant additional capital outlay or increased operating costs (101, 133, 143, 144). Depending on the physical characters of the drying equipment, a combination of increased rate of flow through the driers (up to 50 percent) and higher drying temperatures (up to 150° F. for Caloro rice) is used to achieve increased drier efficiency. The findings are based on tests with rice varieties in southern areas as well as in California.

Calderwood and Hutchinson (17) conducted a series of experiments at Beaumont, Tex., to determine how best to hold freshly harvested rice until it could be dried. These studies, as well as those of Hutchinson and Willms (60), also included the use of unheated air to effect economies in rapidly cooling rice during the tempering periods between passes in the heated air column driers. Long-grain rice, with an initial moisture content below 20 percent, aerated with 0.43 cubic feet per minute per 100 pounds, showed no change in grade when held in temporary aerated storage for 10 days before drying. Medium-grain Gulf-rose, with an initial moisture content of 23 percent, aerated with 0.43 cubic feet per minute per 100 pounds, was not damaged when stored for 3 days. Another lot, with an initial moisture content of 22 percent, aerated with 1.24 cubic feet per minute per 100 pounds for 7 days before drying, showed a sharp drop in grade.

INFRARED DRYING OF ROUGH RICE.—As long ago as the early 1940's, Texas and California rice-growers experimented with industrial infrared lights as a heat source for drying rice. By 1948 California workers had reached the conclusion that infrared rice drying was no faster than convection-type driers, and was not as efficient.⁵ In their six experiments, 7,300 B.t.u.'s were required to remove 1 pound of water from rice, whereas convection-type sack rice driers then in use were using 2,000 B.t.u.'s.

⁵ Unpublished reports from the University of California, Department of Agricultural Engineering.

Infrared drying of rice has not yet become established commercially but interest continues. Schroeder (109, 110) and Schroeder and Rosberg (111, 112) reported on laboratory rice-drying experiments. Varieties apparently respond differently. The drying rate for the 15-, 20-, and 25-second irradiation periods ranged from 1.2 to 1.9 grams of water removed per second of irradiation for Nato and from 1.3 to 1.6 grams for Magnolia. Tilton and Schroeder (138) found that rice weevils and lesser grain borers in rough rice could be controlled by irradiation with infrared lights. They postulated that using gas-fired infrared heating for drying rough rice would have the additional benefit of killing all stages of these stored-rice insects during the rice-drying process.

In utilizing on-farm bin drying and storing, the rice farmer is assuming considerable responsibility for items that he pays someone else to assume when he employs commercial facilities. These include (1) considerable supervision over a long period of time to oversee the drying, particularly if he uses unheated air; (2) greater chance of rice deterioration; (3) protection of the rice from insect, bird, and animal pests; and (4) protection against rain or flood damage. Offsetting these are usually lower cash outlays per unit volume of rice dried and stored.

Dachtler (23) emphasized that the use of the proper airflow rate to dry rice with unheated air is of primary concern in bin drying rice. Air must be supplied at a rate to complete drying before the rice is damaged by mold growth or other causes. Recommendations developed from tests in the Southern States and in California are summarized by Dachtler (23). Supplemental heat is not recommended as a standard practice for bin drying. However, it is desirable to have the necessary equipment available for use during prolonged periods of adverse weather. This normally will include extended periods of high humidity (above 75 percent). The temperature of the air entering the rice may be raised 10° to 15° F. above the ambient temperature. A maximum of 95° is recommended in Texas, and a maximum of 80° to 85° in California. Supplemental heat should be used until the moisture content of the top foot of rice is reduced to 15 percent. After the moisture is reduced to this level, unheated air should be used to complete the drying to a safe storage level. During the time unheated air is used, the fan should be operated only when the relative humidity is less than 75 percent, which usually will be during daylight hours on clear, bright days.

AERATING STORED RICE.—According to Hutchinson and Willms (60), the practice of aerating grain came into widespread use in the Southwest between 1955 and 1960. They indicate aeration is used (1) to maintain the quality of undried

grain until it can be moved through the drier, (2) to remove harvest or drier heat, (3) to remove small amounts of moisture (1 to 2 percent), and (4) to maintain the quality of grain during storage. Aeration is defined as the moving of air through stored grain at low airflow rates (generally between one-tenth and one-fifth cubic feet per minute per 100 pounds) for purposes other than drying, to maintain or improve its value. Several types of aeration systems are described, as are methods of operation and controls.

Aldred (10) presented the following conclusions regarding storage and aeration of rice:

(1) Based on information to date (1952), rice in bulk storage should be turned once every 2 months during the winter and at least once a month during the summer.

(2) With proper aeration, rice with a moisture content of 18 to 24 percent can be kept for a week or 10 days without spoilage.

(3) For retaining rice with a moisture content of 18 to 24 percent before drying, 2 cubic feet per minute per 100 pounds is adequate. After the rice has been partly dried, one-half cubic foot per minute per 100 pounds is adequate.

(4) Rice with a moisture content below 16 percent can be kept several months in either cool or warm weather with the aid of aeration.

As pointed out by Dachtler (23), practically all rough rice is stored in bulk, although sack storage is practical for relatively small lots and for seed rice. A maximum moisture content of 12 percent is recommended for seed rice, but up to 14 percent usually is safe in bulk storage. The length of the storage period for rice depends on market conditions, but it usually is from 5 to 8 months. For any common-type storage bin, any type of construction material is satisfactory if it results in a storage structure that will keep the grain dry, cool, and free of insects and other pests and if it provides job safety and convenience while moving and inspecting the grain. Dachtler warned that if dried rough rice is to be stored for a few months or longer or if damp rice is to be held before drying, the storage structure should be equipped for aeration.

INSECT INFESTATION OF STORED RICE.—Insect infestation generally occurs after rice is in storage, since most rice harvested and dried by modern methods is relatively free of insects upon entering storage (23). Insect control practices that are used before and during storage have been developed through research and are widely applied. Emphasis now is being placed on the use of protective treatment. Chemicals are now available that can be mixed with or sprayed on the rice as it is stored and that will protect it against invading insects yet leave no residues harmful to human beings (108, 140). For infor-

mation about the use of these chemicals, contact your local agricultural authorities.

Stored rice is subject to attack by a number of insects. The lesser grain borer (*Rhyzopertha dominica* (F.)), the Angoumois grain moth (*Sitotroga cerealella* (Oliv.)), and the rice weevil (*Sitophilus oryzae* (L.)) attack sound rough rice kernels. The cadelle (*Tenebroides mauritanicus* (L.)), the saw-toothed grain beetle (*Oryzaeophilus surinamensis* (L.)), the flat grain beetle (*Cryptolestes pusillus* (Schon.)), the red flour beetle (*Tribolium castaneum* (Herbst)), and the confused flour beetle (*T. confusum* (Duv.)) attack broken or dehulled kernels. Moths that infest the surface of bulk or bagged rough rice and spin webbing in profusion include the Indian-meal moth (*Plodia interpunctella* (Hbn.)), the almond moth (*Ephestia cautella* (Wlkr.)), and the rice moth (*Corcyra cephalonica* (Staint.)). In storing bran and milled rice, control of the bran bugs, including the flour beetles, is important (108, 140).

Selected References

- (1) ANONYMOUS.
1947. RICE DRYING AND STORAGE IN LOUISIANA. La. Agr. Expt. Sta. Bul. 416, 22 pp.
- (2) ———
1949. STOP—DON'T PLANT RED RICE. Rice Jour. 52(2): 20.
- (3) ———
1962. UNDERGROUND IRRIGATION. Rice Jour. 65(9): 22, 23, illus.
- (4) ADAIR, C. R.
1940. EFFECT OF TIME OF SEEDING ON YIELD, MILLING QUALITY, AND OTHER CHARACTERS IN RICE. Amer. Soc. Agron. Jour. 32: 697-706.
- (5) ——— and CRALLEY, E. M.
1950. 1949 RICE YIELD AND DISEASE CONTROL TESTS. Ark. Agr. Expt. Sta. Rpt. Ser. 15, 20 pp.
- (6) ——— and ENGLER, KYLE.
1955. THE IRRIGATION AND CULTURE OF RICE. In Water, U.S. Dept. Agr. Yearbook of Agr., pp. 389-394.
- (7) ——— BEACHELL, H. M., JODON, N. E., and others.
1942. COMPARATIVE YIELDS OF TRANSPLANTED AND DIRECT SOWN RICE. Amer. Soc. Agron. Jour. 34: 129-137.
- (8) ——— MILLER, M. D., and BEACHELL, H. M.
1962. RICE IMPROVEMENT AND CULTURE IN THE UNITED STATES. Adv. in Agron. 14: 61-108, illus.
- (9) ADDICOTT, F. T., and LYNCH, R. S.
1957. DEFOLIATION AND DESICCATION: HARVEST-AID PRACTICES. Adv. in Agron. 9: 67-93.
- (10) ALDRED, F. L. (editor).
1953. RECENT RESEARCH ON DRYING AND STORAGE OF ROUGH RICE. South. Coop. Ser. Bul. 29, 29 pp., illus.
- (11) ANDERSON, K. L., and McKIE, J. W.
1962. GROWING RICE IN THE MISSISSIPPI DELTA. Miss. Agr. Ext. Serv. Pub. 219.
- (12) ATKINS, J. G., CRALLEY, E. M., and CHILTON, S. J. P.
1957. UNIFORM RICE SEED TREATMENT TESTS IN ARKANSAS, LOUISIANA, AND TEXAS, 1955-56. Plant Dis. Rptr. 41: 105-108.
- (13) BAINER, R.
1932. HARVESTING AND DRYING ROUGH RICE IN CALIFORNIA. Univ. of Calif., Div. of Agr. Sci. Bul. 541, 29 pp., illus.

- (14) BAMESBERGER, J. G.
1954. LAND LEVELING FOR IRRIGATION. U.S. Dept. Agr. Leaflet 371, 8 pp., illus.
- (15) BARR, H. T., WRATTEN, F. T., POOLE, W. D., and WALKER, R. P.
1955. RECOMMENDATIONS FOR BIN DRYING AND STORAGE OF ROUGH RICE IN LOUISIANA. Rev., La. Agr. Expt. Sta., Agr. Engin. Dept. Cir. 18, 16 pp. [Processed.]
- (16) BLACK, D. E., and WALKER, R. K.
1955. THE VALUE OF PASTURES IN ROTATION WITH RICE. La. Agr. Expt. Sta. Bul. 498, 24 pp., illus.
- (17) CALDERWOOD, D. L., and HUTCHINSON, R. S.
1961. DRYING RICE IN HEATED AIR DRYERS WITH AERATION AS A SUPPLEMENT TREATMENT. U.S. Agr. Market. Res. Rpt. 508, 22 pp.
- (18) CHAMBLISS, C. E.
1920. PRAIRIE RICE CULTURE IN THE UNITED STATES. U.S. Dept. Agr. Farmers' Bul. 1092, 26 pp., illus.
- (19) ——— and JENKINS, J. M.
1925. EXPERIMENTS IN RICE PRODUCTION IN SOUTHWESTERN LOUISIANA. U.S. Dept. Agr. Dept. Bul. 1356, 32 pp., illus.
- (20) CHAPMAN, A. L., and PETERSON, M. L.
1962. THE SEEDLING ESTABLISHMENT OF RICE UNDER WATER IN RELATION TO TEMPERATURE AND DISSOLVED OXYGEN. Crop Sci. 2(5): 391-395.
- (21) CLARK, F., NEARPASS, D. C., and SPECHT, A. W.
1957. INFLUENCE OF ORGANIC ADDITIONS AND FLOODING ON IRON AND MANGANESE UPTAKE BY RICE. Agron. Jour. 49: 586-589.
- (22) CURLEY, R. G., and GOSS, J. R.
1964. ESTIMATING COMBINE LOSSES IN RICE. Univ. Calif., Dept. Agr. Engin., 4 pp. [Unnumbered. Mimeographed.]
- (23) DACHTLER, W. C. (editor).
1959. RESEARCH ON CONDITIONING AND STORAGE OF ROUGH AND MILLED RICE—A REVIEW THROUGH 1958. U.S. Agr. Res. Serv. ARS 20-7, 55 pp., illus.
- (24) DAVIS, J. H., SONNIER, E. A., and WHITE, T. W.
1963. PASTURE-RICE ROTATIONS FOR SOUTHWEST LOUISIANA. La. Agr. 7(1): 4-5.
- (25) DAVIS, L. L.
1944. HARVESTING RICE FOR MAXIMUM MILLING QUALITY IN CALIFORNIA. Rice Jour. 47(3): 3-4, 17-18, illus.
- (26) ———
1950. CALIFORNIA RICE PRODUCTION. Calif. Agr. Ext. Serv. Cir. 163, 55 pp., illus.
- (27) DOCKINS, J. O.
1950. PRODUCING QUALITY SEED RICE DEEMED VITAL TO ARKANSAS RICE INDUSTRY. Rice Jour. 53(5): 21, 35.
- (28) EHRLER, W., and BERNSTEIN, L.
1958. EFFECTS OF ROOT TEMPERATURE, MINERAL NUTRITION, AND SALINITY ON THE GROWTH AND COMPOSITION OF RICE. Bot. Gaz. 120(2): 67-74.
- (29) ENGLER, KYLE.
1958. WATER LEVELS IN RICE IRRIGATION WELLS IN THE GRAND PRAIRIE REGION. Ark. Farm Res. 7(3): 12.
- (30) ——— THOMPSON, D. G., and KAZMANN, R. G.
1945. GROUND WATER SUPPLIES FOR RICE IRRIGATION IN THE GRAND PRAIRIE REGION, ARKANSAS. Ark. Agr. Expt. Sta. Bul. 457, 56 pp., illus.
- (31) EVATT, N. S.
1958. FERTILIZER-WATER DEPTHS TESTS ON RICE, 1956-57. Tex. Agr. Expt. Sta. Prog. Rpt. 2006, 4 pp.
- (32) ——— and BEACHELL, H. M.
1962. SECOND-CROP RICE PRODUCTION IN TEXAS. Tex. Agr. Prog. 8(6): 25-28.
- (33) ——— and WEIHING, R. M.
1957. FERTILIZER REQUIREMENTS FOR RICE IN RICE-PASTURE ROTATIONS. Tex. Agr. Expt. Sta. Prog. Rpt. 1948, 4 pp.
- (34) FAULKNER, M. D.
1960. WATER PLANTING STUDIES. Rice Jour. 63(7): 49-50.
- (35) ——— and MIEARS, R. J.
1962. LEVELING RICE LAND IN WATER. La. Agr. 5(4): 3, 16, illus.
- (36) FINFROCK, D. C., and MILLER, M. D.
1958. ESTABLISHING A RICE STAND. Univ. of Calif. Div. of Agr. Sci. Leaflet 99, 12 pp., illus.
- (37) ——— RANEY, F. M., MILLER, M. D., and BOOHER, L. J.
1960. WATER MANAGEMENT IN RICE PRODUCTION. Univ. of Calif. Div. of Agr. Sci. Leaflet 131, 2 pp., illus.
- (38) ——— VISTE, K. L., HARVEY, W. A., and MILLER, M. D.
1957. WEED CONTROL IN RICE. Univ. of Calif. Div. of Agr. Sci. Leaflet 97, 2 pp., illus.
- (39) GARRISON, R. H.
1959. GOOD SEED DOES NOT COST, IT PAYS HANDSOME DIVIDENDS. Seedmen's Digest, Aug., pp. 22, 23, 44, illus.
- (40) GATTIS, J. L., KOCH, K. A., and McVEY, J. L.
1959. LAND GRADING FOR SURFACE IRRIGATION. Ark. Agr. Ext. Serv. Cir. 491, 29 pp., illus.
- (41) GAY, B.
1961. 'RATOONING' METHODS OF A TEXAS RICE FARMER. Rice Jour. 64(2): 22.
- (42) GERLOW, A., and MULLINS, T.
1958. RESERVOIRS FOR IRRIGATION IN THE GRAND PRAIRIE AREA: AN ECONOMIC APPRAISAL. Ark. Agr. Expt. Sta. Bul. 606, 24 pp.
- (43) GOSS, W. L., and BROWN, E.
1939. BURIED RED RICE SEED. Agron. Jour. 31: 633-637.
- (44) GRAY, L. C., and THOMPSON, E. K.
1941. HISTORY OF AGRICULTURE IN THE SOUTHERN U. S. TO 1860. Carnegie Inst. Wash. Pub. 430. Peter Smith, New York. [Reprinted in 2 vols.]
- (45) GREEN, B. L.
1961. FISH FARMING; PAST, PRESENT, FUTURE. Ark. Agr. Econ. 3(4): 1, 2.
- (46) ——— and MULLINS, T.
1959. USE OF RESERVOIRS FOR PRODUCTION OF FISH IN THE RICE AREAS OF ARKANSAS. Ark. Agr. Expt. Sta. Spec. Rpt. 9, 16 pp.
- (47) ——— and WHITE, J. H.
1963. COMPARISON OF THREE SELECTED ROTATIONS IN EASTERN ARKANSAS. Ark. Agr. Expt. Sta. Bul. 664, 20 pp., illus.
- (48) HALICK, J. V.
1960. EFFECT OF TEMPERATURE DURING RIPENING ON QUALITY CHARACTERISTICS OF RICE. Rice Tech. Working Group Proc., June 29 to July 1, Lafayette, La. MP 488, p. 14.
- (49) HALL, H. V.
1959. GREENHOUSE STUDIES ON THE RELATION OF WATER MANAGEMENT TO THE GROWTH OF RICE. Ark. Agr. Expt. Sta. Rpt. Ser. 89, 22 pp.
- (50) ———
1960. WATER SEEDING OF RICE IN ARKANSAS. Rice Jour. 63(13): 13.
- (51) ——— and THOMPSON, L. F.
1962. SALINITY AND ALKALINITY OF RICE SOILS IN ARKANSAS. Ark. Farm Res. 11(2): 11.

- (52) HASKELL, C. G.
1915. IRRIGATION PRACTICE IN RICE GROWING. U.S. Dept. Agr. Farmers' Bul. 673, 12 pp.
- (53) HENDERSON, S. M.
1954. THE CAUSES AND CHARACTERISTICS OF RICE CHECKING. *Rice Jour.* 57(5): 16, 18.
- (54) ———
1955. DEEP-BED RICE DRIER PERFORMANCE. *Agr. Engin.* 36: 817-820.
- (55) ———
1958. DEEP-BED GRAIN DRYING ON THE RANCH WITH UNHEATED AIR. Univ. of Calif. Div. of Agr. Sci. Leaflet 103, 2 pp.
- (56) HILDRETH, R. J., and SORENSON, J. W., JR.
1957. PROFITS AND LOSS FROM ON-FARM DRYING AND STORAGE OF RICE IN TEXAS. *Tex. Agr. Expt. Sta. Bul.* 865, 16 pp.
- (57) HINKLE, D. A.
1952. FIELD DRYING OF RICE BY CHEMICALS. *South. Weed Conf. Proc.* 5: 175-177.
- (58) ———
1953. EFFECT OF PRE-HARVEST CHEMICALS UPON COMBINE EFFICIENCY AND MILLING YIELD OF RICE. *South. Weed Conf. Proc.* 6: 72-75.
- (59) ———
1954. PRE-HARVEST TREATMENT OF RICE AS AN AID IN DRYING. *Rice Tech. Working Group Proc.* 6: 16-17.
- (60) HUTCHINSON, R. S., and WILLMS, E. F.
1962. OPERATING GRAIN AERATION SYSTEMS IN THE SOUTHWEST. U.S. Dept. Agr. Market Res. Rpt. 512, 20 pp., illus.
- (61) HURST, W. M., and HUMPHRIES, W. R.
1955. HARVESTING WITH COMBINES. U.S. Dept. Agr. Farmers' Bul. 1761, 40 pp., illus.
- (62) JENKINS, J. M., and JONES, J. W.
1944. RESULTS OF EXPERIMENTS WITH RICE IN LOUISIANA. *La. Agr. Expt. Sta. Bul.* 384, 39 pp.
- (63) JODON, N. E.
1953. GROWING PERIOD OF LEADING RICE VARIETIES WHEN SOWN ON DIFFERENT DATES. *La. Agr. Expt. Sta. Bul.* 476, 8 pp.
- (64) JOHNSTON, T. H., ADAIR, C. R., TEMPLETON, G. E., and others.
1963. NOVA AND VEGOLD—NEW RICE VARIETIES. *Ark. Agr. Expt. Sta. Bul.* 675, 24 pp., illus.
- (65) ——— and CRALLEY, E. M.
1955. RICE VARIETIES AND THEIR YIELDS IN ARKANSAS, 1948-1954. *Ark. Agr. Expt. Sta. Rpt. Ser.* 49, 20 pp.
- (66) ——— CRALLEY, E. M., and HENRY, S. F.
1959. PERFORMANCE OF RICE VARIETIES IN ARKANSAS, 1953-1958. *Ark. Agr. Expt. Sta. Rpt. Ser.* 85, 31 pp., illus.
- (67) JONES, J. W., ADAIR, C. R., JODON, N. E., and others.
1947. EFFECT OF ENVIRONMENT AND SOURCE OF SEED ON YIELD AND OTHER CHARACTERS IN RICE. *Amer. Soc. Agron. Jour.* 39: 874-886.
- (68) ——— DAVIS, L. L., and WILLIAMS, A. H.
1950. RICE CULTURE IN CALIFORNIA. U.S. Dept. Agr. Farmers' Bul. 2022, 32 pp., illus.
- (69) ——— 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.
- (70) ——— M.
1938. RICE CULTURE IN THE UNITED STATES. U.S. Dept. Agr. Farmers' Bul. 1808, 29 pp., illus.
- (71) KAPP, L. C.
1947. THE EFFECT OF COMMON SALT ON RICE PRODUCTION. *Ark. Agr. Expt. Sta. Bul.* 465, 7 pp.
- (72) KESTER, E. B.
1955. EFFECTS OF CERTAIN PREPROCESSING AND CULTURAL VARIABLES UPON MILLING AND OTHER PROCESSING QUALITIES OF RICE. *Calif. Rice Res. Symp. Proc.*, Albany, Calif., pp. 6-12.
- (73) ——— and PENCE, J. W.
1962. RICE INVESTIGATIONS AT WESTERN REGIONAL RESEARCH LABORATORY. *Rice Jour.* 65(7): 45-47, illus.
- (74) KING, B. M.
1937. THE UTILIZATION OF WABASH CLAY (GUMBO) SOILS IN CROP PRODUCTION. *Mo. Agr. Expt. Sta. Bul.* 254, pp. 12-32.
- (75) LEWIS, D. C., SCOTT, V. H., MUELLER, K. E., and others.
1962. NEW RICE LEVEE CONCEPTS. *Rice Jour.* 65(4): 6-15.
- (76) MCFARLANE, V. H., HOGAN, J. T., and McLEMORE, T. A.
1955. EFFECTS OF HEAT TREATMENT ON THE VIABILITY OF RICE. U.S. Dept. Agr. Tech. Bul. 1129, 51 pp., illus.
- (77) MACKIE, W. W.
1943. RICE IN THE IMPERIAL VALLEY (CALIFORNIA). *Imp. Rice Growers' Coop. Assoc.* [Unnumbered Rpt.]
- (78) McNEAL, XZIN.
1949. ARTIFICIAL DRYING OF COMBINED RICE. *Ark. Agr. Expt. Sta. Bul.* 487, 30 pp.
- (79) ———
1950. EFFECT OF COMBINE ADJUSTMENT ON HARVEST LOSSES OF RICE. *Ark. Agr. Expt. Sta. Bul.* 500, 26 pp., illus.
- (80) ———
1950. WHEN TO HARVEST RICE FOR BEST MILLING QUALITY AND GERMINATION. *Ark. Agr. Expt. Sta. Bul.* 504, 41 pp.
- (81) ———
1961. EFFECTS OF DRYING TECHNIQUES AND TEMPERATURES ON HEAD RICE YIELDS. *Ark. Agr. Expt. Sta. Bul.* 640, 22 pp., illus.
- (82) MARR, J. C.
1957. GRADING LAND FOR SURFACE IRRIGATION. Univ. of Calif. Div. Agr. Sci. Cir. 438, 48 pp., illus.
- (83) MIKKELSEN, D. S., FINFROCK, D. C., and MILLER, M. D.
1958. RICE FERTILIZATION. *Calif. Agr. Expt. Sta. Ext. Serv. Leaflet* 96, 12 pp., illus.
- (84) ——— and SINAH, M. N.
1961. GERMINATION INHIBITION IN *ORYZA SATIVA* AND CONTROL BY PREPLANTING SOAKING TREATMENTS. *Crop Sci.* 1: 332-335.
- (85) MORRISON, S. R.
1953. RICE IRRIGATION TESTS AT THE BEAUMONT STATION, 1952. *Tex. Agr. Expt. Sta. Prog. Rpt.* 1542, 2 pp.
- (86) ——— DAVIS, W. C., and SORENSON, J. W., JR.
1954. BIN DRYING OF RICE AT THE RICE-PASTURE EXPERIMENT STATION, 1953-54. *Tex. Agr. Expt. Sta. Prog. Rpt.* 1670, 9 pp.
- (87) MUCKEL, D. C.
1959. REPLENISHING UNDERGROUND WATER SUPPLIES ON THE FARM. U.S. Dept. Agr. Leaflet 452, 8 pp., illus.
- (88) MULLINS, T.
1954. ECONOMIC APPRAISAL OF FARMING PRACTICES AND ROTATION PROGRAMS ON LOUISIANA RICE FARMS. *La. Agr. Expt. Sta. Bul.* 491, 40 pp.
- (89) ———
1960. PRODUCTION PRACTICES, COSTS AND RETURNS FOR MAJOR ENTERPRISES ON RICE FARMS IN THE DELTA AREA OF MISSISSIPPI. *Miss. Agr. Expt. Sta. Bul.* 595, 24 pp.

- (90) MULLINS, T., and SLUSHER, M. W.
1950. COMPARISON OF FARMING SYSTEMS FOR SMALL RICE FARMS IN ARKANSAS. Ark. Agr. Expt. Sta. Bul. 498, 44 pp., illus.
- (91) ——— and SLUSHER, M. W.
1951. COMPARISON OF FARMING SYSTEMS FOR LARGE RICE FARMS IN ARKANSAS. Ark. Agr. Expt. Sta. Bul. 509, 40 pp.
- (92) NELSON, G. S.
1961. AERIAL APPLICATIONS OF GRANULAR AND PELLETED MATERIALS AND SEEDS. Rice Jour. 64(7): 26-27.
- (93) NELSON, M.
1931. PRELIMINARY REPORT ON CULTURAL AND FERTILIZER EXPERIMENTS WITH RICE IN ARKANSAS. Ark. Agr. Expt. Sta. Bul. 264, 46 pp.
- (94) ———
1944. ROTATION, CULTURAL AND IRRIGATION PRACTICES AFFECTING RICE PRODUCTION. Ark. Agr. Expt. Sta. Bul. 445, 45 pp.
- (95) OVERSTREET, R., and SCHULZ, R. E.
1958. THE EFFECT OF RICE CULTURE ON A NON-SALINE SODIC SOIL OF THE FRESNO SERIES. Hilgardia 27(12): 319-332, illus.
- (96) PEARSON, G. A.
1959. FACTORS INFLUENCING SALINITY OF SUBMERGED SOILS AND GROWTH OF CALORO RICE. Soil Sci. 87(4): 198-206.
- (97) ———
1961. THE SALT TOLERANCE OF RICE. Internat. Rice Comm. Newsletter 10(1): 1-4.
- (98) ——— and AYERS, A. D.
1960. RICE AS A CROP FOR SALT-AFFECTED SOIL IN PROCESS OF RECLAMATION. U.S. Dept. Agr. Prod. Res. Rpt. 43, 13 pp., illus.
- (99) ——— and BERNSTEIN, L.
1959. SALINITY EFFECTS AT SEVERAL GROWTH STAGES OF RICE. Agron. Jour. 51: 654-657.
- (100) PERKINS, W. R., and LUND, C. F.
1950. CROP ROTATION ON RICE FARMS. Ark. Agr. Ext. Serv. Leaflet 184.
- (101) POMINSKI, J., WASSERMAN, T., SPADARO, J. J., and others.
1961. IMPROVEMENTS IN COMMERCIAL DRYING OF SOUTHERN GROWN RICE. I. ZENITH—A MEDIUM-GRAIN VARIETY. Rice Jour. 64(9): 10, 12-13, 16-17.
- (102) RANEY, F. C.
1959. WARMING BASINS AND WATER TEMPERATURE. Calif. Rice Res. Symp. Proc., Albany, Calif., pp. 20-23.
- (103) ———, HAGAN, R. M., and FINFROCK, D. C.
1957. WATER TEMPERATURE IN IRRIGATION. Calif. Agr. 11(4): 19, 20, 37, illus.
- (104) REED, J. F., and STURGIS, M. B.
1936. TOXICITY FROM ARSENIC COMPOUNDS TO RICE ON FLOODED SOILS. Amer. Soc. Agron. Jour. 28: 432-436.
- (105) REYNOLDS, E. B.
1954. RESEARCH ON RICE PRODUCTION IN TEXAS. Tex. Agr. Expt. Sta. Bul. 775, 29 pp., illus.
- (106) ROBERTSON, R. D.
1917. IRRIGATION OF RICE IN CALIFORNIA. Calif. Agr. Expt. Sta. Bul. 279, pp. 253-270, illus.
- (107) ROLSTON, L. H., and ROUSE, PHIL.
1960. CONTROL OF GRAPE COLASPIS AND RICE WATER WEEVIL BY SEED OR SOIL TREATMENT. Ark. Agr. Expt. Sta. Bul. 624, 10 pp.
- (108) ROUSE, PHIL., ROLSTON, L. H., and LINCOLN, C.
1958. INSECTS . . . IN FARM-STORED RICE. Ark. Agr. Expt. Sta. Bul. 600, 25 pp.
- (109) SCHROEDER, H. W.
1960. INFRA-RED DRYING OF ROUGH RICE. II. SHORT GRAIN TYPE—CALROSE AND CALORO. Rice Jour. 63(13): 6-8, 25-28.
- (110) ———
1961. INFRA-RED DRYING OF ROUGH RICE. III. MEDIUM-GRAIN TYPE—NATO AND MAGNOLIA. Rice Jour. 64(1): 11-12, 24-27, illus.
- (111) ——— and ROSBERG, D. W.
1959. DRYING ROUGH RICE WITH INFRA-RED RADIATION. Tex. Agr. Expt. Sta. MP-354 (May), 4 pp.
- (112) ——— and ROSBERG, D. W.
1960. INFRA-RED DRYING OF ROUGH RICE. I. LONG-GRAIN TYPE—REXORC AND BLUEBONNET 50. Rice Jour. 63(12): 3-5, 23-27, illus.
- (113) SCOTT, V. H., LEWIS, D. C., FOX, D. K., and LANE, A. F.
1961. PLASTIC LEVEES FOR RICE IRRIGATION. Calif. Agr. 15(11): 8, 9.
- (114) SENEWIRATNE, S. T., and MIKKELSEN, D. S.
1961. PHYSIOLOGICAL FACTORS LIMITING GROWTH AND YIELDS OF ORYZA SATIVA UNDER UNFLOODED CONDITIONS. Plant and Soil 14: 127-146.
- (115) SIMMONS, C. F.
1940. RICE PRODUCTION AND RICELAND USES IN ARKANSAS. Ark. Agr. Ext. Serv. Cir. 424, 16 pp.
- (116) SIMS, J. L.
1961. FISH-RICE PROJECT PLANS. Rice Jour. 64(7): 22.
- (117) ———
1964. NITROGEN AVAILABILITY IN RICE FIELD AND RESERVOIR SOILS. Ark. Farm Res. 13(2).
- (118) ———
1964. GROWTH OF ARABLE CROPS AS A MEANS OF REDUCING AVAILABLE NITROGEN IN RESERVOIR SOIL. Ark. Farm Res. 13(3).
- (119) SLUSHER, M. W.
1952. THE USE OF AIRPLANES ON RICE FARMS IN ARKANSAS. Ark. Agr. Expt. Sta. Bul. 541, 20 pp.
- (120) ———
1955. ENTERPRISE COSTS AND RETURNS ON RICE FARMS. Ark. Agr. Expt. Sta. Bul. 549, 34 pp., illus.
- (121) ——— and MULLINS, T.
1948. MECHANIZATION OF THE RICE HARVEST. Ark. Agr. Expt. Sta. Rpt. Ser. 11, 32 pp., illus.
- (122) ——— and MULLINS, T.
1952. RICE MILL YIELD AND GRADE IN RELATION TO VARIETY AND METHOD OF HARVEST. Ark. Agr. Expt. Sta. Bul. 526, 36 pp., illus.
- (123) SMITH, R. J., JR., HINKLE, D. A., and WILLIAMS, F. J.
1959. PRE-HARVEST DESICCATION OF RICE WITH CHEMICALS. Ark. Agr. Expt. Sta. Bul. 619, 16 pp., illus.
- (124) SMITH, W. D.
1940. HANDLING ROUGH RICE TO PRODUCE HIGH GRADES. U.S. Dept. Agr. Farmers' Bul. 1420, 21 pp., illus.
- (125) ———, DEFFES, J. J., BENNETT, C. H., and HURST, W. M.
1930. DRYING COMBINE HARVESTED RICE ON THE FARM. U.S. Dept. Agr., U.S. Grain Standards Act-Grain Investigations 51, 20 pp.
- (126) ———, DEFFES, J. J., BENNETT, C. H., and others.
1933. ARTIFICIAL DRYING OF RICE ON THE FARM. U.S. Dept. Agr. Cir. 292, 24 pp., illus.
- (127) ———, DEFFES, J. J., BENNETT, C. H., and others.
1938. EFFECT OF DATE OF HARVEST ON YIELD AND MILLING QUALITY OF RICE. U.S. Dept. Agr. Cir. 484, 20 pp.
- (128) SONNIER, A.
1960. CATFISH, CRAYFISH AND RICE. Rice Jour. 63(5): 6, 8, 9, illus.

- (129) SORENSON, J. W., JR.
1957. SUPPLEMENTAL HEAT FOR DRYING RICE IN FARM STORAGE BINS. Tex. Agr. Expt. Sta., Dept. Agr. Engin., 9 pp. [Processed Rpt.]
- (130) ———
1958. RECOMMENDATIONS FOR DRYING AND STORING RICE IN FARM STORAGE BINS. Tex. Agr. Expt. Sta., Dept. Agr. Engin. [Processed Rpt.]
- (131) ——— and DAVIS, W. C.
1955. DRYING AND STORING ROUGH RICE IN FARM STORAGE BINS, 1954-55. Tex. Agr. Expt. Sta. Prog. Rpt. 1819, 8 pp.
- (132) ——— DAVIS, W. C., and HOLLINGSWORTH, J. P.
1948. DRYING RICE IN SACKS. Tex. Agr. Expt. Sta. Prog. Rpt. 1138, 4 pp.
- (133) SPADARO, J. J.
1961. EVALUATION OF WRRL DRYING METHODS ON SOUTHERN RICE. Second Conf. on Rice Utilization Proc., May 18-19. U.S. Dept. Agr., Agr. Res. Serv. ARS 74-24, pp. 22-23.
- (134) STANSEL, J. W., HALICK, J. V., and KRAMER, H. H.
1961. INFLUENCE OF TEMPERATURE ON HEADING DATES AND GRAIN CHARACTERISTICS OF RICE. Rice Tech. Working Group Proc., June 29 to July 1, Lafayette, La. MP 488, pp. 14-15.
- (135) STROMBERG, L. K., and YAMADA, H.
1955. WATER QUALITY IN RICE FIELDS. Calif. Agr. 9(3): 10.
- (136) SULLIVAN, K. B.
1960. WATER IS A 'CROP' WITH ROTATION RESERVOIRS. Ark. Farmer 62(8): 4, illus.
- (137) THOMPSON, W. R., and WALLER, T. M.
1952. GROWING RICE IN THE MISSISSIPPI DELTA. Miss. Agr. Ext. Serv. Pub. 219, 6 pp.
- (138) TILTON, E. W., and SCHROEDER, H. W.
1961. THE EFFECT OF INFRARED RADIATION ON IMMATURE INSECTS IN KERNELS OF ROUGH RICE. Rice Jour. 64(9): 23-25.
- (139) TULLIS, E. C.
1951. HERBICIDES FOR ACCELERATING MATURATION OF RICE. South. Weed Conf. Proc. 4: 1-2.
- (140) UNITED STATES DEPARTMENT OF AGRICULTURE.
1957. CONTROLLING INSECT PESTS OF STORED RICE. U.S. Dept. Agr. Agr. Handb. 129, 30 pp., illus.
- (141) WALKER, R. K., and STURGIS, M. B.
1946. A TWELVE-MONTH GRAZING PROGRAM FOR THE RICE AREA OF LOUISIANA. La. Agr. Expt. Sta. Bul. 407, 19 pp.
- (142) WASSERMAN, T., FERREL, R. E., BROWN, A. H., and SMITH, G. S.
1957. COMMERCIAL DRYING OF WESTERN RICE. Cereal Chem. Today 2(9): 251-254.
- (143) ——— FERREL, R. E., KAUFMAN, V. F., and others.
1958. IMPROVEMENTS IN COMMERCIAL DRYING OF WESTERN RICE. I. MIXING TYPE DRYER—LOUISIANA STATE UNIVERSITY DESIGN. Rice Jour. 61(4): 30-32, 34-36, 38; 61(5): 40, 42-46.
- (144) ——— FERREL, R. E., KAUFMAN, V. F., and others.
1958. IMPROVEMENTS IN COMMERCIAL DRYING OF WESTERN RICE. II. NON-MIXING COLUMNAR-TYPE DRYER. Rice Jour. 61(7): 9-12, 14.
- (145) WASSON, R. A., and WALKER, R. K.
1955. LOUISIANA RICE. La. Agr. Ext. Serv. Ext. Pub. 1182, 16 pp., illus.
- (146) WEIHING, R. M., MONCRIEF, J. B., and DAVIS, W. C.
1950. YEARLONG GRAZING IN THE RICE-PASTURE SYSTEM OF FARMING. Tex. Agr. Expt. Sta. Prog. Rpt. 1280, 4 pp.
- (147) WILLIAMS, A. H.
1952. PRE-HARVEST DRYING OF RICE BY CHEMICAL TREATMENT. Down to Earth 8(2): 2-3.
- (148) ——— and FINFROCK, D. C.
1962. EFFECT OF PLACEMENT AND TIME OF INCORPORATION OF VETCH ON RICE YIELDS. Agron. Jour. 54(6): 547-549.
- (149) ——— FINFROCK, D. C., and MILLER, M. D.
1957. GREEN MANURES AND CROP RESIDUES IN MANAGING RICE SOILS. Calif. Agr. Expt. Sta. Ext. Serv. Leaflet 90, 6 pp.
- (150) WYCHE, R. H., and CHEANEY, R. L.
1955. WATER SEEDING OF RICE. Tex. Agr. Expt. Sta. Prog. Rpt. 1778, 3 pp.

CAUTION.—If pesticides are handled or applied improperly, or if unused parts are disposed of improperly, they may be injurious to humans, domestic animals, desirable plants, pollinating insects, fish or other wildlife, and may contaminate water supplies. Use pesticides only when needed and handle them with care. Follow the directions and heed all precautions on the container label.

WEEDS AND THEIR CONTROL

By R. J. SMITH, JR., and W. C. SHAW

Losses in the rice crop due to weed competition amount to more than \$60 million each year. In addition, farmers spend almost \$24 million each year to control weeds. Among the weeds that cause severe losses in rice are barnyardgrass (*Echinochloa* spp.), red rice (*Oryza sativa* L.), signalgrass (*Brachiaria* spp.), sprangletop (*Lepidochloa* spp.), sesbania (*Sesbania exaltata* (Raf.) Cory), curly indigo (*Aeschynomene virginica* (L.) B.S.P.), Mexican-weed (*Caperonia castaneaefolia* (L.) St. Hil.), gooseweed (*Sphenoclea zeylanica* Gaertn.), redstem (*Ammannia coccinea* Rottb.), ducksalad (*Heteranthera* spp.), bulrush (*Scirpus* spp.), umbrellasedge (*Cyperus* spp.), spikerush (*Eleocharis* spp.), and various species of algae.

Conditions favorable for growth of rice also are favorable for growth of these weeds. Weeds in rice produce an abundance of viable seeds; and once weeds infest the soil, they are difficult to remove. The best approach to weed control is to prevent weed infestations by seeding weed-free rice and by removing scattered weed seedlings from the field before they produce seed. Even after weeds infest the soil, however, they can be effectively controlled by selected cultural and chemical methods.

Weed control is the primary aim of many cultural practices. Herbicides—notably propanil and the phenoxy herbicides—have been used in conjunction with good farming practices for controlling weeds and have greatly increased the effectiveness of the cultural practices. As chemical methods of weed control change—and they are changing rapidly—cultural practices also will change.

Certain young grass and broadleaf weeds in rice were effectively controlled in 1959 by propanil [3,4-dichloropropionanilide]. Propanil is very selective, and rice is not injured by high rates applied soon after emergence. In 1961 rice farmers in the major ricegrowing States used propanil as a postemergence weed killer in commercial fields on about 20,000 acres. Because propanil controlled grass weeds so effectively in 1961, and because it was recommended by the agricultural experiment stations in Arkansas, Mississippi, and Texas, rice farmers treated approximately 250,000 acres in 1962. Overall, good-to-excellent grass and weed control and significant

improvement in rice yields were obtained in more than 90 percent of the fields treated in 1962.

Propanil controls barnyardgrass, including the species *Echinochloa crusgalli* (L.) Beauv., *E. colonum* (L.) Link, and *E. crusgavonis* (H.B.K.) Schult.; and other grasses, including crabgrass (*Digitaria* spp.), Texas-millet (*Panicum texanum* Buckl.), paragrass (*P. purpurascens* Raddi), and signalgrass (*Brachiaria* spp.). Propanil also controls certain young annual broadleaf weeds including sesbania, curly indigo, gooseweed, and redstem; and young annual sedges, including spikerush, umbrellasedge, and *Fimbristylis* spp. Propanil controls all these weeds most effectively when they are in the early vegetative stage of growth.

Propanil kills the cells of grass-weed and broadleaf-weed plants by contact action. It is usually applied when both the weeds and the rice are in the early stages of development. Barnyardgrass and other grass weeds are controlled most effectively when propanil is applied in the 2- to 3-leaf stage, or when the grass is 2 to 3 inches tall. However, rapidly growing grass weeds in highly fertile soil and deep water may be controlled satisfactorily when the grass weeds have four or more leaves.

Propanil should be applied according to the developmental stage of the grass weed rather than that of the rice. However, a reasonably heavy stand of rice should be growing before treatment; otherwise if replanting is necessary, the effectiveness of the herbicide is lost.

Irrigation stimulates the growth of grass weeds and makes them more susceptible to propanil, but water should not be standing on fields when propanil is applied because propanil cannot reach weeds covered with water. Fields treated with propanil should be flooded 1 to 4 days after treatment to increase the activity of the herbicide on barnyardgrass and to prevent barnyardgrass and other grass-weed plants from reinfesting the field.

Propanil may be applied with either ground or aerial equipment. Aerial equipment has the advantage because fields may be sprayed when the soil is too wet to support ground equipment, and also levees do not present a problem as with ground equipment. The spray solution of propanil should cover the weeds adequately and uniformly but should not be allowed to drift onto nearby areas where it can injure field crops such

as cotton and soybeans and certain horticultural and ornamental plants. Young cotton and soybean plants are susceptible to propanil until they are 8 to 10 inches tall and can be killed or injured severely enough to reduce yields greatly.

Postemergence treatments with phenoxy herbicides control most broadleaf and aquatic weeds and many sedges that infest rice. Grass weeds are not controlled. Phenoxy herbicides are often used by commercial ricegrowers, and more than half of the rice crop in the United States is sprayed each year for broadleaf-weed control.

Phenoxy herbicides used for controlling broadleaf weeds in rice include 2,4-D [2,4-dichlorophenoxyacetic acid], MCPA [2-methyl-4-chlorophenoxyacetic acid], 2,4,5-T [2,4,5-trichlorophenoxyacetic acid], and silvex [2-(2,4,5-trichlorophenoxy)propionic acid]. These herbicides are applied as either amine salt or low-volatile ester formulations at rates of $\frac{1}{2}$ to $1\frac{1}{2}$ pounds per acre acid equivalent. The rate depends on the weed species and the stage of growth of the rice.

Response of rice to phenoxy herbicides is affected chiefly by the stage of development of the rice plant. Very young rice is injured severely or even killed by 2,4-D, MCPA, 2,4,5-T, and silvex. Rice in late-jointing, booting, or heading stages may be injured severely. Rice in the late-tillering or prejointing stages is usually uninjured by phenoxy herbicides. Rice responds differently to these various postemergence herbicides. It is most "tolerant" to 2,4,5-T, less "tolerant" to silvex and MCPA, and least "tolerant" to 2,4-D.

Weeds also respond differently to 2,4-D, MCPA, 2,4,5-T, and silvex. When several species varying in susceptibility to a herbicide are present in one ricefield, mixtures of phenoxy herbicides may be used advantageously. Weeds are usually most susceptible to phenoxy herbicides when they are young and growing rapidly. Therefore, it is important to treat weeds as soon as the rice is adequately "tolerant" to the herbicide—usually about 7 weeks after rice emerges.

Water management affects the response of weeds to phenoxy herbicides. Herbicides are less effective in reaching weed plants that are covered by water, and herbicides cannot effectively control weeds that are growing slowly because of dry soil. Therefore, herbicides should be applied soon after draining, while weeds are growing rapidly. If the field is flooded too soon after spraying or if rain falls immediately after spraying, the herbicide is washed off the weed plants and cannot control their growth.

Phenoxy herbicides are sprayed uniformly to the field with low-gallonage sprayers attached to ground or aerial equipment. Care must be taken not to injure other crops such as cotton, soybeans, and tomatoes and valuable trees, shrubs, and ornamental plants. All major rice-producing States strictly regulate aerial applications of phenoxy herbicides. Most States regulate ground applications. These laws prohibit the use of high-volatile esters of 2,4-D, MCPA, 2,4,5-T, and silvex. Definite regulations as to equipment, herbicide formulations, wind velocity, records, responsibility, and liability must be observed. Before spraying rice with postemergence herbicides, farmers and custom applicators should become familiar with State laws so they can comply with them.

CAUTION.—Before being used for applying insecticide or fungicide, spray equipment that has been used for applying 2,4-D, 2,4,5-T, MCPA, or silvex should be given a special cleansing with ammonia or with activated charcoal and detergent. For detailed instructions, consult your State extension weed specialist.

Certain algae may be controlled with applications of small copper sulfate crystals applied in the early stages of scum development. Differences in the species of algae and in local water and soil conditions determine the amount of control possible. Copper may be toxic to fish, so care must be taken if water from treated ricefields is collected in reservoirs containing fish.

RICE DISEASES

By J. G. ATKINS

Rice diseases are economically important in the rice crop in the southern rice area (3).¹ Except for seedling disorders, these diseases are of no importance in California. Annual losses in Louisiana and Texas average about 8 percent. Diseases are important in rice, but they are not as disastrous in rice as in many other crops. Although average losses in most fields are rather low, losses in individual fields from specific diseases are sometimes high.

Most of the world's important rice diseases are known to occur in the United States. Exceptions are the rice dwarf and rice stripe viruses, bacterial leaf blight, and certain physiological

disturbances reported from Japan and other Asiatic countries. A few minor diseases caused by fungi are also not known to occur in the United States.

The severity of specific diseases is influenced by varietal susceptibility, fertilization, soil type, and environmental conditions. Losses from certain diseases can be reduced or held to a low level by the use of resistant varieties, better cultural and management practices, and seed treatment. Diseases shift in prevalence and severity with changes in varieties. The reaction of 18 rice varieties to some diseases in the United States are shown in table 19.

TABLE 19.—*Reaction of rice varieties to some diseases of rice in the United States*

[R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible; VS = very susceptible]

Grain type and variety	Blast	Brown leaf spot	Narrow brown leaf spot	Straighthead	White tip	Hoja blanca
Short-grain:						
Caloro -----	S	S	S	S	S	S
Cody -----	S	S	S	S	S	S
Colusa -----	S	MS	S	S	S	R
Medium-grain:						
Arkrose -----	S	S	S	S	VS	R
Calrose -----	VS	MS	MS	S	VS	S
Gulfrose -----	R, S	MS	R	S	S	R
Magnolia -----	S	MS	S	S	S	S
Nato -----	S	MS	MS	MS	S	S
Northrose -----	S	S	S	MR	S	MR
Zenith -----	R, S	MS	S	S	S	S
Long-grain:						
Belle Patna -----	S	S	S	R	R	S
Bluebonnet 50 -----	MS	S	S	R	R	S
Century Patna 231 --	S	S	MS	VS	R	S
Rexoro -----	S	S	VS	VS	R	S
Sunbonnet -----	MS	S	S	VS	R	S
Texas Patna -----	S	S	VS	R	R	S
Toro -----	S	S	MS	R	R	S
TP 49 -----	S	S	MS	VS	R	S

Major Diseases

Blast

Blast, caused by the fungus *Piricularia oryzae* Cav., occurs in all ricegrowing areas of the world and is the most damaging disease of rice (fig. 39). Blast in the United States is about as old as the rice crop itself—it caused trouble

shortly after rice was introduced into South Carolina (22) and then into Louisiana (18). Losses from blast were light from about 1935 to 1955; however, in the southern rice area, particularly Louisiana, seriously infested fields have been found each year since 1955 (9). Blast has been one of the chief factors in preventing successful rice culture in southern Florida.

When the fungus attacks the leaves, the disease results in leaf blast. Symptoms are elongated or spindle-shaped leaf spots with grayish

¹ Italic numbers in parentheses refer to Selected References, p. 120.

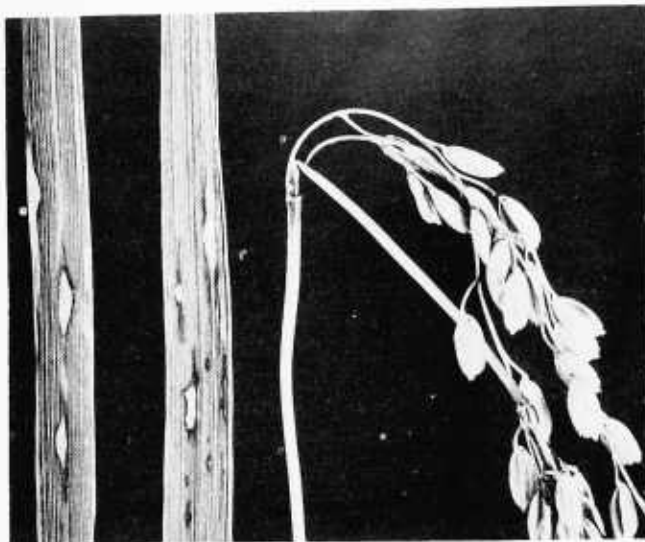


FIGURE 39.—The long, narrow spots on the leaves and the infection at the base of the panicle, which caused it to break over, are typical symptoms of blast. (Photo courtesy of G. E. Templeton.)

centers and brown margins. Under severe disease conditions, nearly all leaves are killed and many young plants are killed or severely damaged. Young plants are also killed by infection of the sheath tissues, which turn brown. Generally, all plants in a ricefield are not uniformly affected. In some areas the plants are killed, but in others they are affected less severely. The leaves are susceptible from the seedling through the early-tillering stage of growth. Under flooded soil conditions, the leaves are less susceptible in the late-tillering stage of growth and at heading. As a result, severely diseased fields of young rice appear to recover later when the plants become older and progress through the vegetative growth stages.

Head blast, also called rotten neck, results from the attack of the fungus after emergence of the panicle (head) from the boot or top leaf sheath. The peduncle (the top node and internode) and the branches of the panicle are very susceptible to attack. Typically, the peduncle shows a necrotic, brown area that prevents movement of food into the developing grain. The grain produced in affected panicles varies from nearly normal amounts to none, depending on the time of infection in relation to flowering. As infection weakens the structural tissues of the peduncle, the panicles frequently break over to give the condition known as rotten neck.

Atmospheric moisture conditions are of primary importance in infection and spread of the fungus that causes blast (19). Frequent rains, heavy nightly dews, and high relative humidities favor disease development. Severe outbreaks of the disease occur after periods of rainy weather.

Rice plants under high levels of nitrogen fertilization are susceptible to blast. Plants growing under nonflooded or upland conditions are more susceptible than those growing under flooded or irrigated conditions (19). For this reason, blast is often heavier on the levees and on or around knolls or other high areas in the ricefield than it is on the low areas.

All United States rice varieties are susceptible to one or more of the 10 pathogenic races of *P. oryzae* known to occur in the southern rice area (4, 20). However, Rexoro, Texas Patna, and TP 49 usually escape infection because they are late maturing. Under average field conditions, Bluebonnet 50 and Sunbonnet are less severely infected than are several other varieties, and losses are lighter. Arkrose, Caloro, Calrose, Colusa, Nato, and Northrose are consistently susceptible. Gulfrose and Zenith are resistant to most races. The reaction of 18 varieties to 10 races is given in table 20.

Brown Leaf Spot

Brown leaf spot of rice is caused by *Helminthosporium oryzae* B. de Haan, the same fungus that causes seedling blight. The spots occur chiefly on the leaves but are frequently on the hulls (fig. 40). The leaf spots are oval to circular and grayish brown to black.

Brown leaf spot is prevalent in the southern rice area. Under good cultural conditions, damage is slight on vigorous plants. Weak plants with yellowish leaves, caused by low nitrogen levels, root damage, or other factors unfavorable for good nitrogen nutrition, are often severely damaged by brown leaf spot.

All commercial rice varieties are susceptible to brown leaf spot. Bluebonnet 50 is generally more susceptible than are most other varieties. Management and fertilizer practices that promote good growth reduce losses.

Narrow Brown Leaf Spot

Narrow brown leaf spot in rice, caused by the fungus *Cercospora oryzae* I. Miyake, is one of the most prevalent rice diseases in the southern rice area. The leaf spots are narrow or linear and light to dark brown (fig. 41). When severe, the leaves die, one after another, beginning with the lower leaves. In most seasons, infection does not become severe until late August or September. Early-maturing rice varieties, when sown early, tend to escape heavy infection.

Rice varieties show marked differences in susceptibility. Several pathogenic races or strains of *C. oryzae* occur in the United States (23). Bluebonnet 50, Rexoro, and Texas Patna are susceptible varieties. Under average field conditions, Century Patna 231, Gulfrose, Nato, Toro, and TP 49 are fairly resistant.

TABLE 20.—*Reaction of rice varieties to the races of Piricularia oryzae Cav. in the United States*
[R = resistant; MR = moderately resistant; S = susceptible]

Grain type and variety	Race									
	1	2	3	4	5	6	7	8	10	16
Short-grain:										
Caloro.....	R	S	S	S	R	S	S	S	R	S
Cody.....	R	MR	S	S	R	S	S	S	R	-----
Colusa.....	R	S	S	S	R	S	S	S	R	-----
Medium-grain:										
Arkrose.....	R	S	S	S	R	S	S	S	R	S
Calrose.....	R	S	S	S	R	S	S	S	R	-----
Gulfrose.....	S	R	R	R	R	R	S	R	R	R
Magnolia.....	R	R	S	R	R	S	S	R	R	S
Nato.....	R	R	S	R	R	S	S	R	R	S
Northrose.....	R	S	S	S	R	S	S	R	R	S
Zenith.....	S	R	R	R	R	R	S	R	R	R
Long-grain:										
Belle Patna.....	S	R	S	R	R	S	S	S	R	R
Bluebonnet 50.....	S	R	S	R	R	S	S	R	R	S
Century Patna 231.....	S	R	S	R	R	S	MR	R	R	R
Rexoro.....	S	R	S	R	R	S	S	S	R	R
Sunbonnet.....	S	R	S	R	R	S	S	S	R	-----
Texas Patna.....	S	R	S	R	R	S	S	S	R	R
Toro.....	S	R	S	R	R	S	S	S	R	S
TP 49.....	S	R	S	R	R	S	S	S	R	R

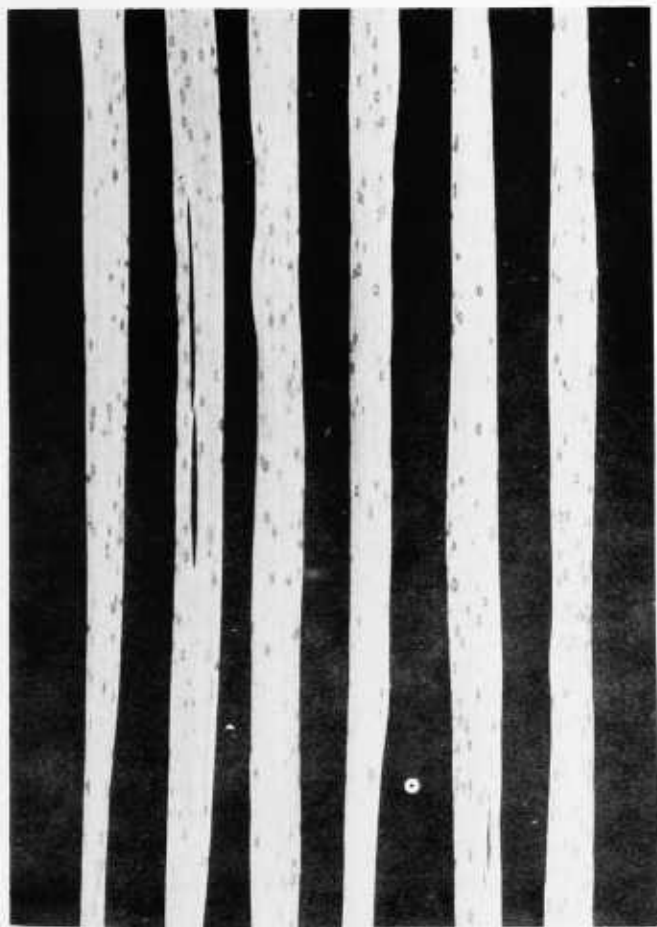


FIGURE 40.—Oval to circular lesions on rice leaves are symptoms of brown leaf spot.



FIGURE 41.—Linear lesions on rice leaves are symptoms of narrow brown leaf spot.

Root Rot

Root rot of rice is a general diseased condition in which the roots grow poorly, darken with necrosis, or die. As decay progresses, the leaves cease to grow normally and turn yellow. Affected plants generally show heavy brown leaf

spot because of their impaired physiological condition.

Several soil fungi may cause root rot. Damage is more severe when nematodes and root maggots feed on the roots. Plants growing in saline soil and alkali spots in fields are also affected.

Losses from root disorders can be held to a minimum through good cultural and fertilizing practices that maintain the plants in a vigorous condition. Draining the field and permitting the soil to dry stimulates growth of new roots. For many years growers have used this practice to control root maggots and straighthead in conjunction with topdressing applications of nitrogen.

Seedling Blight

Fungi in the soil and on or in the seed cause seedling blight of rice (fig. 42). These fungi reduce emergence and kill or weaken the plant after emergence. Low soil temperature and high soil moisture, combined with seedborne fungi, or combinations of the two, make stand establishment difficult.

Satisfactory stands are generally obtained through use of good-quality seed treated with a fungicide and seeded under conditions favorable for rapid emergence. Atkins, Cralley, and Chilton (7) reported that thiram, chloranil, dichlone, and a number of organic mercurys gave best results. Seedling blight caused by *Helminthosporium oryzae*—the fungus that causes brown leaf spot—can be partly controlled by using one of the mercury fungicides. Each of the chemicals listed is available in different preparations.

WARNING

The materials recommended here for treating rice seed should be considered poisonous to man and animals. Care should be taken in handling and using them. Read the label placed on each container by the manufacturer and follow his instructions regarding safety measures. All workmen operating seed-treating equipment should be carefully taught how to use the chemicals and should be warned against carelessness. Sacks of treated seed should always be properly labeled. Care should be taken to prevent any treated seed from being used as food or feed.

Stem Rot

The stem rot fungus *Leptosphaeria salvinii* Catt. (*Sclerotium oryzae* Catt.) lives in the soil as sclerotia from one season to another up to 6 years (30) (fig. 43). Typically, rice plants are attacked in the advanced-growth stages. Initially, the fungus invades the sheath tissues near the water level and produces dark areas. The



FIGURE 42.—Three blighted rice seedlings and, at right, a healthy seedling.

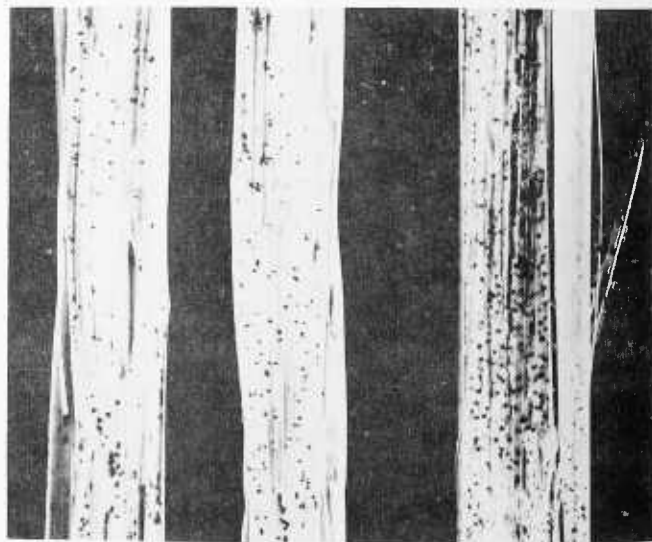


FIGURE 43.—Rice culms showing sclerotia of the stem rot fungus. (Photo courtesy of G. E. Templeton.)

fungus progresses inward to the culm. The nodes and internodes turn dark and weaken. Many of the plants lodge because of rotten culms. The plants are weakened or killed before maturity. Little grain is produced and its quality is reduced.

None of the rice varieties are highly resistant to stem rot (14). Rexoro is perhaps the most susceptible variety. Some of the medium-grain varieties are resistant or intermediate in reaction. The early-maturing varieties tend to escape severe damage if seeded early. High rates of nitrogen fertilizer increase the susceptibility of plants to stem rot damage, but potassium fertilizers reduce damage.

Straighthead

Straighthead, sometimes called blight, is a non-parasitic or physiological disease of rice. Diagnostic symptoms are observed only in the panicles. The panicles remain upright at maturity because of lack of grain development (fig. 44); hence, the common name of straighthead. The shape of the palea and lemma, which later form the hulls, is distorted, particularly in the long-grain varieties. It is similar to a parrot beak, crescent, or half moon. Hull distortion may or may not be conspicuous in the short- and medium-grain varieties.

Straighthead is caused by unknown soil conditions associated with prolonged submergence of the soil with water. Undecayed organic material and arsenic in the soil are also factors. In

general, rice grown on the lighter or sandy soils is more subject to straighthead than rice grown on the heavier clay soils.

For many years, ricegrowers have followed the practice of draining and drying the soil to prevent straighthead (27). The fields are drained, dried, and reflooded just before panicle formation. This period is about 50 days after seedling emergence for Century Patna 231, a susceptible, early-maturing variety (13). However, the best control measure is to use resistant varieties.

The numerous rice varieties have been classified as to straighthead reaction (6). Belle Patna, Bluebonnet 50, Lacrosse, Texas Patna, and Toro are resistant. Nato is intermediate in reaction and is seldom affected.

White Tip

White tip of rice is caused by an ectoparasitic, foliar nematode, *Aphelenchoides besseyi* Christie (fig. 45). The nematodes are seedborne and live from one crop to the next in the seed rice. After rice is sown, the nematodes become active and move into the growing point of the young rice plants. In this protected location, the nematodes feed and reproduce. The feeding by large numbers of nematodes injures the developing leaves and panicles before emergence. The injury is later observed as white, necrotic leaf tips and small, usually sterile panicles. Grain yields in susceptible plants are greatly reduced.

Several methods may be used to control white



FIGURE 44.—Erect panicles with sterile florets are typical of rice plants affected with straighthead.

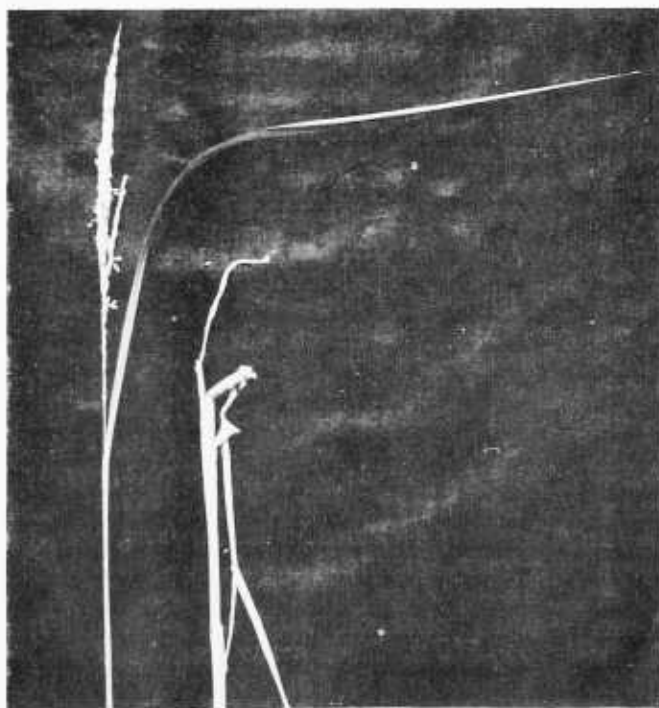


FIGURE 45.—Left, healthy rice panicle; right, panicle affected with white tip.

tip. Resistant varieties or nematode-free seed may be sown. Cralley (15) and Todd and Atkins (28) have described hot-water treatments that control white tip very effectively. They are not practical for general use. However, they can be used by the rice experiment stations for treating small lots of base seed used in foundation seed programs. Emergence through water following water seeding controls white tip (16). This practice can also be used to clean up small lots for seed production.

Several rice varieties are resistant to white tip (table 1). In general, the long-grain varieties are resistant and most of the short- and medium-grain varieties are susceptible (12). Although white tip was an economically important disease in the southern rice area for many years, it is no longer important.

Minor Diseases

Bordered Sheath Spot

Bordered sheath spot in rice is caused by *Rhizoctonia oryzae* Ryker & Gooch. The sheath spots are large, 2 to 6 centimeters long, and frequently encircle the sheath. The margins of the spots are reddish brown. During wet weather, the leaves of rice plants in small areas, 2 to 6 feet in diameter, are killed by *Rhizoctonia* spp.

Hoja Blanca

Hoja blanca, or white leaf, is a virus disease of rice that is transmitted by a planthopper, *Sogatia orizicola* Muir. Leaf symptoms are one or more white stripes along the leaf blade or a whitening of the entire leaf blade (fig. 46). Diseased plants are generally reduced in height.

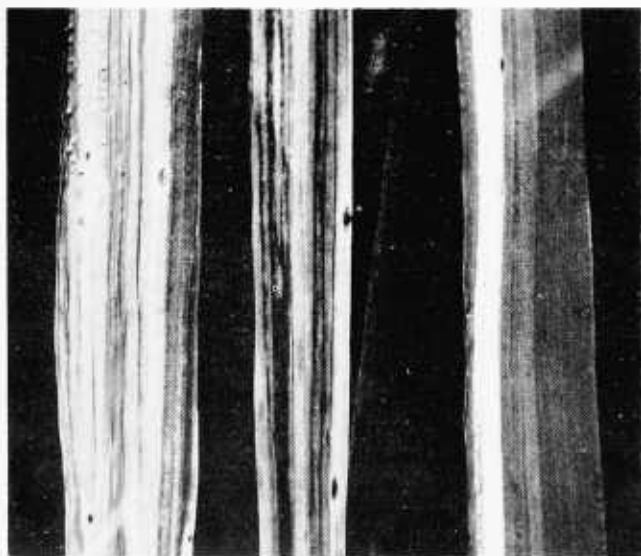


FIGURE 46.—Rice leaves affected with hoja blanca.

The panicles are reduced in size and often fail to emerge completely from the boot. The palea and lemma are generally distorted in shape and later turn brown. Most florets are sterile. Since the diseased plants produce few, if any, seed, the panicles remain upright instead of bending over like those of normal plants (fig. 47).

Hoja blanca occurs only in the Western Hemisphere. Leaf symptoms are similar to those of the stripe virus disease of Japan, but the two diseases differ (8). Hoja blanca was first recognized as a new rice disease in 1956 (2). Severe yield losses were reported from Cuba, Venezuela, and other countries of Latin America. The disease and insect vector were found in 1957 in Florida (5), in 1958 in southern Mississippi (10), and in 1959 in Louisiana (11). An eradication program was initiated after each finding of the insect vector. In 1960 and 1961, neither the disease nor the insect vector was found in the southern rice States. In 1962, *S. orizicola* was again found and collected in southern Louisiana (1).

Yield losses from hoja blanca in the United States have been negligible. Unless the disease and insect vector become established and cause economic losses, no control measures need be con-



FIGURE 47.—Rice panicles affected with hoja blanca.

sidered by individual rice producers. Arkrose, Colusa, and Gulfroze are resistant to hoja blanca.

Kernel Smut

Kernel smut of rice is caused by one of the smut fungi, *Neovossia barclayana* Bref. (31). Part or all of the endosperm is replaced by a black mass of smut spores (fig. 48). One to several grains per panicle are affected. Other plant parts are not affected. The disease is easily overlooked in the field. It can be seen when rains wash the black spores over portions of the panicle or when the smut spore mass expands between the two hulls with absorption of moisture from dew or rain.

The black smut spores germinate and produce sporidia. When the rice flowers open at pollination, the sporidia enter. The fungus then invades the developing grain, grows, and produces its spores. Infection is not systemic in the rice plant, as it is with several other cereal smut fungi (24). Although the smut spores are seedborne (that is, they are carried into a field along with the seed), they are not directly responsible for later smut infection. Kernel smut is more prevalent in rainy seasons and in fields receiving fairly high rates of nitrogen fertilizer (25). Nitrogen applied late in the season also increases the incidence of kernel smut.

No satisfactory controls for kernel smut are known at present. Seed treatment by chemicals or hot water is ineffective. All long-grain varieties are susceptible. Most of the medium-grain

varieties, except Nato, generally show less kernel smut.

Kernel Spots

Discolored or dark areas and spots occur on the kernels of brown and milled rice. This kernel discoloration is generally associated with dark, discolored hulls. *Curvularia lunata* (Wakk.) Boed., *Fusarium* spp., *Alternaria* spp., *Trichoconis caudata* (Appel & Strunk) Clements, and *Helminthosporium oryzae* are the fungi most commonly isolated (29). Feeding punctures of the immature grains by stink bugs also cause kernel spots (17).

At the time of some of the earlier studies (21, 26, 29), rice was binder harvested and placed in shocks. The change in harvesting methods from the binder to the combine has probably reduced losses from kernel spots.

Leaf Smut

Leaf smut, caused by *Entyloma oryzae* H. & P. Syd., is a common but minor rice disease in the southern rice area (fig. 49). The disease may be recognized by numerous, small, black sori on the leaves. The disease becomes more prevalent as the rice plants approach maturity.



FIGURE 48.—Rice panicle with several florets affected by kernel smut.

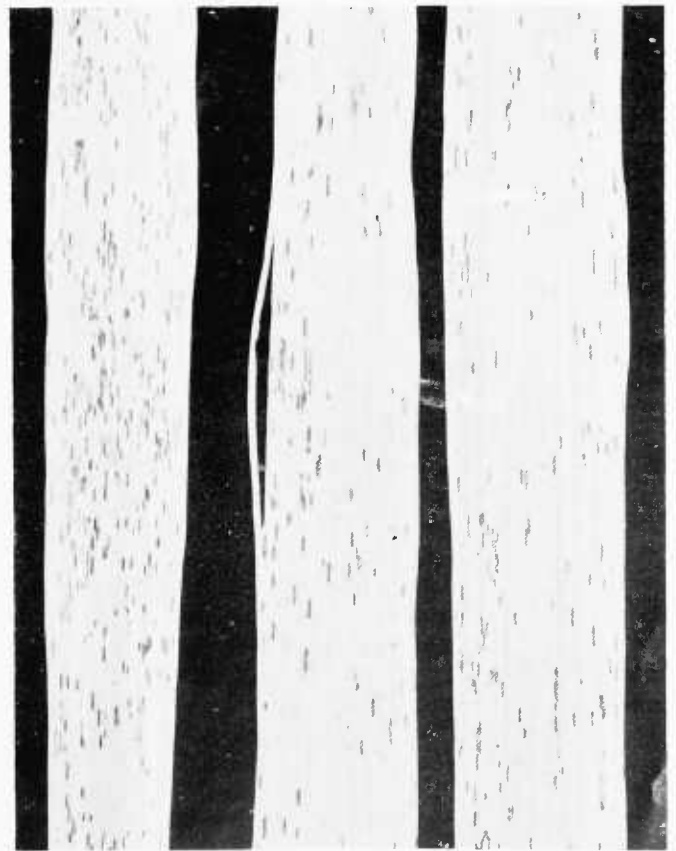


FIGURE 49.—Leaf smut on rice leaves.

Selected References

- (1) ANONYMOUS
1962. INSECT CARRIER OF HOJA BLANCA RICE DISEASE REAPPEARS IN LOUISIANA. *Rice Jour.* 65(12): 22.
- (2) ADAIR, C. R., and INGRAM, J. W.
1957. PLANS FOR THE STUDY OF HOJA BLANCA—A NEW RICE DISEASE. *Rice Jour.* 60(4): 12.
- (3) ATKINS, J. G.
1958. RICE DISEASES. U.S. Dept. Agr. Farmers' Bul. 2120, 14 pp.
- (4) ———
1962. PREVALENCE AND DISTRIBUTION OF PATHOGENIC RACES OF *PIRICULARIA ORYZAE* IN THE UNITED STATES. *Phytopathology* 52: 2.
- (5) ——— and ADAIR, C. R.
1957. RECENT DISCOVERY OF HOJA BLANCA, A NEW RICE DISEASE IN FLORIDA, AND VARIETAL RESISTANCE TESTS IN CUBA AND VENEZUELA. *Plant Dis. Rptr.* 41: 911-915.
- (6) ——— BEACHELL, H. M., and CRANE, L. E.
1956. REACTION OF RICE VARIETIES TO STRAIGHTHEAD. *Tex. Agr. Expt. Sta. Prog. Rpt.* 1865, 2 pp.
- (7) ——— CRALLEY, E. M., and CHILTON, S. J. P.
1957. UNIFORM RICE SEED TREATMENT TESTS IN ARKANSAS, LOUISIANA, AND TEXAS. *Plant Dis. Rptr.* 41: 105-108.
- (8) ——— GOTO, K., and YASUO, S.
1961. COMPARATIVE REACTIONS OF RICE VARIETIES TO THE STRIPE AND HOJA BLANCA VIRUS DISEASES. *Internl. Rice Comm. Newsletter* 10(4): 5-8.
- (9) ——— JODON, N. E., and BOLICH, C. N.
1962. TESTING AND BREEDING FOR BLAST-RESISTANT RICE. *La. Agr.* 5(4): 14-15.
- (10) ——— KRAMER, J. P., and HENSLEY, S. D.
1958. HOJA BLANCA AND ITS INSECT VECTOR FOUND ON RICE IN A SECOND AREA IN THE UNITED STATES. *Plant Dis. Rptr.* 42: 1414.
- (11) ——— NEWSOM, L. D., SPINK, W. T., and others.
1960. OCCURRENCE OF HOJA BLANCA AND ITS VECTOR, *SOBATA ORIZICOLA* MUIR, ON RICE IN LOUISIANA. *Plant Dis. Rptr.* 44: 390-393.
- (12) ——— and TODD, E. H.
1959. WHITE TIP DISEASE OF RICE. III. YIELD TESTS AND VARIETAL RESISTANCE. *Phytopathology* 49: 189-191.
- (13) CHEANEY, R. L.
1955. EFFECT OF TIME OF DRAINING OF RICE ON THE PREVENTION OF STRAIGHTHEAD. *Tex. Agr. Expt. Sta. Prog. Rpt.* 1774, 5 pp.
- (14) CRALLEY, E. M.
1936. RESISTANCE OF RICE VARIETIES TO STEM ROT. *Ark. Agr. Expt. Sta. Bul.* 329, 31 pp.
- (15) ———
1949. WHITE TIP OF RICE. (Abstract) *Phytopathology* 39: 5.
- (16) ———
1956. A NEW CONTROL MEASURE FOR WHITE TIP. *Ark. Farm Res.* 5(4): 5.
- (17) DOUGLAS, W. A., and TULLIS, E. C.
1950. INSECTS AND FUNGI AS CAUSES OF PECKY RICE. U.S. Dept. Agr. Tech. Bul. 1015, 20 pp.
- (18) FULTON, H. R.
1908. DISEASES AFFECTING RICE IN LOUISIANA. *La. Agr. Expt. Sta. Bul.* 105, 28 pp.
- (19) KAHN, R. P., and LIBBY, J. L.
1958. THE EFFECT OF ENVIRONMENTAL FACTORS AND PLANT AGE ON THE INFECTION OF RICE BY THE BLAST FUNGUS, *PIRICULARIA ORYZAE*. *Phytopathology* 48: 25-30.
- (20) LATTERELL, FRANCES M., TULLIS, E. C., and COLLIER, J. W.
1960. PHYSIOLOGIC RACES OF *PIRICULARIA ORYZAE* CAV. *Plant Dis. Rptr.* 44: 679-683.
- (21) MARTIN, A. L., and ALSTATT, G. E.
1940. BLACK KERNEL AND WHITE TIP OF RICE. *Tex. Agr. Expt. Sta. Bul.* 584, 14 pp.
- (22) METCALF, H.
1906. A PRELIMINARY REPORT ON THE BLAST OF RICE WITH NOTES ON OTHER RICE DISEASES. *S.C. Agr. Expt. Sta. Bul.* 121, 48 pp.
- (23) RYKER, T. C.
1943. PHYSIOLOGIC SPECIALIZATION IN *CERCOSPORA ORYZAE*. *Phytopathology* 33: 70-74.
- (24) TEMPLETON, G. E.
1961. LOCAL INFECTION OF RICE FLORETS BY THE KERNEL SMUT ORGANISM, *TILLETIA HORRIDA*. *Phytopathology* 51: 130-131.
- (25) ——— JOHNSTON, T. H., and HENRY, S. E.
1960. KERNEL SMUT OF RICE. *Ark. Farm Res.* 9(6): 10.
- (26) TISDALE, W. H.
1922. SEEDLING BLIGHT AND STACK-BURN OF RICE AND THE HOT-WATER SEED TREATMENT. U.S. Dept. Agr. Dept. Bul. 1116, 11 pp.
- (27) ——— and JENKINS, J. M.
1921. STRAIGHTHEAD OF RICE AND ITS CONTROL. U.S. Dept. Agr. Farmers' Bul. 1212, 16 pp.
- (28) TODD, E. H., and ATKINS, J. G.
1959. WHITE TIP DISEASE OF RICE. II. SEED TREATMENT STUDIES. *Phytopathology* 49: 184-188.
- (29) TULLIS, E. C.
1936. FUNGI ISOLATED FROM DISCOLORED RICE KERNELS. U.S. Dept. Agr. Tech. Bul. 540, 11 pp.
- (30) ——— and CRALLEY, E. M.
1941. LONGEVITY OF *SCLEROTIA* OF THE STEM-ROT FUNGUS *LEPTOSPHAERIA SALVINII*. *Phytopathology* 31: 279-281.
- (31) ——— and JOHNSON, A. G.
1952. SYNONYMY OF *TILLETIA HORRIDA* AND *NEOVOSIA BARCLAYANA*. *Mycologia* 44: 773-788.

INSECTS AND THEIR CONTROL

By TRAVIS EVERETT

Rice Water Weevil

The rice water weevil (*Lissorhoptrus oryzophilus* Kuschel) occurs in most of the rice-growing areas of the United States. The adult weevil (fig. 50) is grayish brown and about one-eighth inch long. It overwinters in finely matted grasses growing in the vicinity of ricefields. In the spring it migrates into the ricefields and feeds on newly emerged plants, making slitlike, longitudinal feeding scars on the upper surface of the leaves. Eggs are laid in the leaf sheaths of rice plants. Larvae feed on the roots of rice plants and cause severe injury by pruning the root system. The young larvae, or root maggots as they are commonly called, are milky white, legless, and about one-half inch long when fully grown.

Since the immature stages of the rice water weevil are spent entirely under water among the rice roots, many of the larvae may be destroyed by drainage (6).¹ However, this practice is not recommended for controlling the root maggots because it is unreliable and also impractical in areas where water supplies are not abundant.

¹ *Italic numbers in parentheses refer to Selected References, p. 124.*

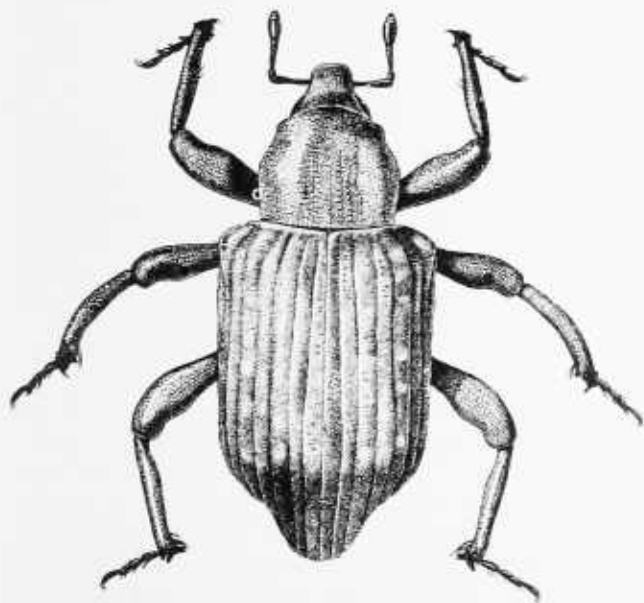


FIGURE 50.—Adult rice water weevil.

The rice water weevil can be effectively controlled with insecticides.

Rice Stink Bug

Practically all ricefields in Arkansas, Louisiana, and Texas are infested with the rice stink bug (*Oebalus pugnax* (Fabricius)). The adult stink bug (fig. 51) is a straw-colored, shield-shaped insect about one-half inch long. It passes the winter as an adult in the refuse near the surface of the ground in clumps of grass. It emerges from winter quarters in the spring and feeds on grasses and sedges. Two or three generations may be produced there before it migrates to rice soon after the rice begins to head. The eggs, shaped like short cylinders, are deposited on the leaves, stems, or heads of the rice, on grass, on Mexican-weed, and on other weeds. The eggs are usually laid in clusters of 10 to 40 in 2 rows,

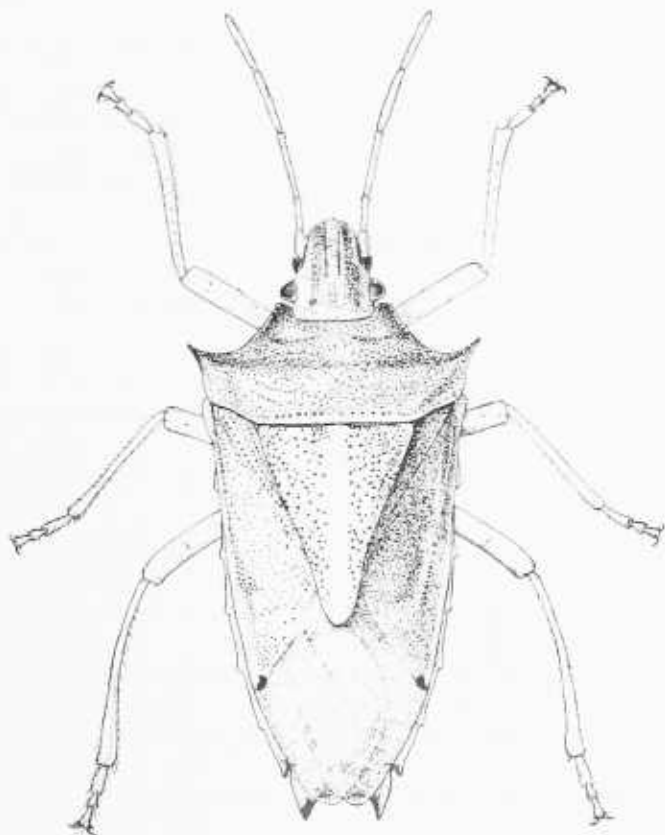


FIGURE 51.—Adult rice stink bug.

are green when first laid, and change to reddish black before hatching. The freshly hatched nymph is nearly round, about $1\frac{1}{2}$ millimeters long and 1 millimeter wide. The head, thorax, legs, and antennae are black; the abdomen is red with two elongate black spots running crosswise. The young stink bugs remain together near the eggshells until after the first molt. Then they seek separate feeding places, generally on grass or on rice panicles, where they suck the juice from the developing kernels. Feeding in the milk stage of rice produces empty glumes, whereas feeding in the soft-dough stage causes "peckiness" of grain or seed sterility (4).

Since infestations build up on grasses earlier in the season, control of grasses in the field and mowing the areas around the field help reduce the potential population for infesting rice. Two hymenopterous egg parasites, *Ooencyrtus anasae* (Ashm.) and *Telenomus podisi* Ashm., are at times very helpful in reducing stink bug populations late in the season.

Grape Colaspis

The grape colaspis (*Maecolaspis flavida* (Say)), called lespedeza worm by ricegrowers, sometimes reduces plant stands severely in Arkansas and Louisiana (9). It passes the winter in the young larval stage. In the spring the larvae make their way toward the soil surface where they feed on germinating seeds or seedlings. Heavy infestations may reduce stands so severely that reseeding is necessary. The larvae pupate in the soil and emerge as pale brown, elliptical beetles about one-eighth inch long. Adults of the grape colaspis lay their eggs in the soil around the roots of grasses growing in lespedeza or other leguminous crops. Rice planted following these crops is subject to damage.

Other Pests of Rice

Several other pests occasionally cause serious damage to rice.

The rice leaf miner (*Hydrellia griseola* var. *scapularis* Loew) is a pest of rice in California (7). Maggots of this fly feed in the leaves of young rice plants and destroy the leaf tissue. Infested leaves turn brown and lie prostrate on the water. This pest is seldom present in sufficient numbers to warrant control measures.

Grasshoppers are found in nearly all ricefields, but seldom are present in sufficient numbers to cause severe damage (2). They feed on the leaves, culms, and grain of rice.

Sporadic outbreaks of the fall armyworm (*Spodoptera frugiperda* (J. E. Smith)) (fig. 52) have been recorded at irregular intervals and in

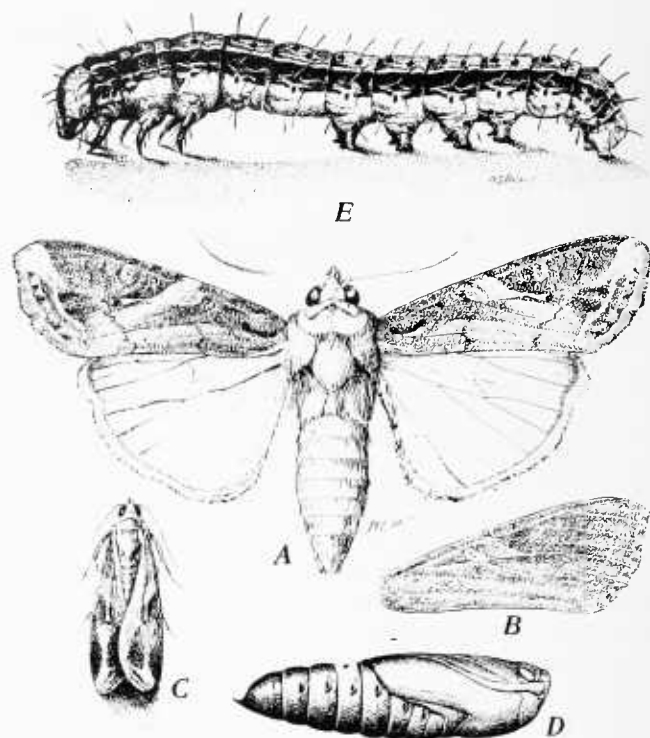


FIGURE 52.—Fall armyworm: A, Male moth; B, right front wing of female moth; C, moth in resting position; D, pupa; E, full-grown larva. A, B, D, E about $\times 2$; C slightly enlarged.

widely separated localities. It feeds on leaves and stems of unflooded rice. Submerging the rice crop is usually effective in controlling this insect.

The rice stalk borer (*Chilo plejadellus* Zincken) (fig. 53) and the sugarcane borer (*Diatraea saccharalis* (Fabricius)) (fig. 54) both occur in rice-

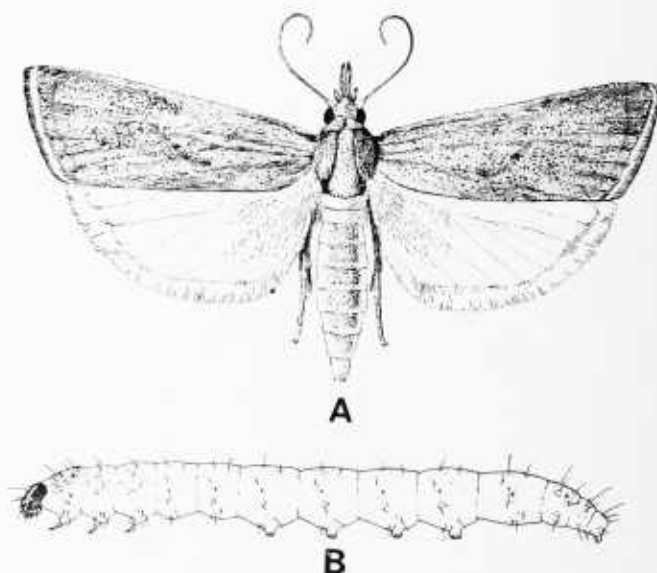


FIGURE 53.—Rice stalk borer: A, Adult; B, larva. About $\times 3$.

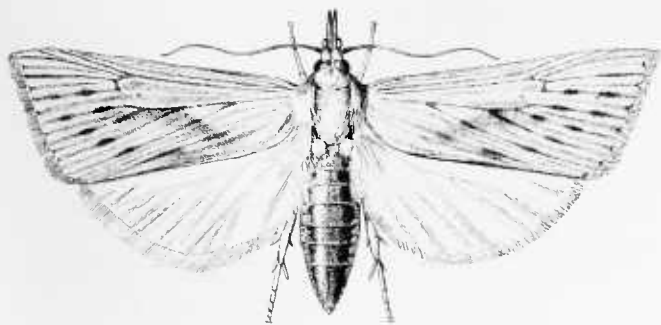


FIGURE 54.—Adult female sugarcane borer.

fields in Louisiana and Texas (3). These borers tunnel inside the stem throughout the growing season and interfere with normal growth and development of the plant. They may also weaken the stem so that it breaks off or lodges before harvest. Stalk borer damage is first noticeable on the rice plant at time of heading when sterile heads with white panicles, or white heads as they are commonly called, appear. The eggs of both species of borers are parasitized by the minute wasp (*Trichogramma minutum* Riley), which helps reduce insect populations. Plowing under rice stubble in the spring destroys some of the overwintering borers. Grazing with cattle or flooding rice stubble fields reduces the number of hibernating borers. Ricefields should be separated as far as possible from corn and sugarcane because these two crops serve as a breeding place for the sugarcane borer.

The planthopper (*Sogatia orizicola* Muir) is potentially a very important pest of rice. It is the only known vector of hoja blanca, the rice disease that has become the scourge of rice production in several Latin American countries. *S. orizicola* was first reported in the United States in 1957. Although the planthopper was found in Mississippi in 1958 and in Louisiana in 1959 (1) and in 1962, neither it nor the disease it transmits has become established in the United States. Apparently the vector cannot survive the cold weather that sometimes occurs in the rice-growing areas of this country.

The chinch bug (*Blissus leucopterus* (Say)) (fig. 55) is present in Arkansas, Louisiana, and Texas (3). It has entered ricefields in large numbers and seriously injured the young rice plants before they were submerged. Both adults and nymphs attack rice. The feeding of bugs causes the plants to wither and die. Chinch bugs feed mainly on the stems, just above the surface of the ground. They may be controlled by submerging the infested field. The insects spend the winter in dry grass, straw, and other material that affords them shelter. Plowing under such material in the fall or winter reduces

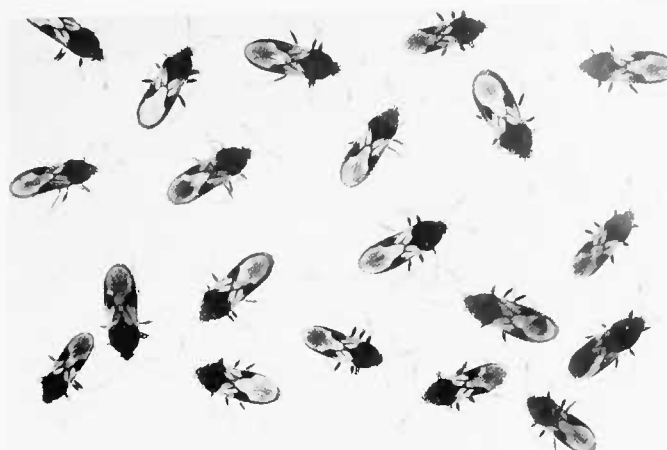


FIGURE 55.—Chinch bugs. Enlarged.

the number of bugs emerging the following spring.

The tadpole shrimp (*Triops longicaudatus* (LeConte)), although not an insect, is sometimes a pest in California (10). Damage occurs shortly after fields are flooded and when eggs laid in fields the previous year hatch. Shrimp larvae at first feed on organic matter in the soil; but as they mature, they dislodge and feed on young rice plants. The shrimp matures in 8 to 10 days and may produce a second generation.

For information on the insecticides currently recommended for control of rice insects, consult your county agent, State agricultural experiment station, or the U.S. Department of Agriculture, Washington, D. C. 20250.

PRECAUTIONS

Insecticides are poisonous. Use them only when needed and handle them with care. Follow the directions and heed all precautions on the container label. Insecticides should be kept in closed, well-labeled containers, in a dry place where they will not contaminate food or feed and where children and pets cannot reach them. Avoid repeated or prolonged contact with skin and inhalation of dusts and mists. Methyl parathion and phosphamidon should be applied only by persons experienced in handling and applying poisonous chemicals. Operators exposed to sprays containing methyl parathion and phosphamidon should wear half masks equipped with cartridges of a type approved by the U.S. Department of Agriculture. Wear clean, dry clothing, and wash hands and face before eating or smoking. When handling concentrates, avoid spilling them on the skin and keep them out of the eyes, nose, and mouth. If any is spilled, wash it off the skin and change clothing immediately. If it gets in the eyes, flush with plenty

of water for 15 minutes and get medical attention.

Avoid drift of insecticide sprays or dusts to nearby crops, livestock, or bee yards. Sprays or dusts applied by airplane and other power equipment are especially likely to drift. Do not allow poultry, dairy animals, or meat animals to feed on plants or drink water contaminated by drift of insecticides. Do not clean spraying equipment or dump excess spray material near streams, lakes, or ponds.

Do not apply—

Aldrin or malathion within 7 days before harvest.

Carbaryl (Sevin)² within 14 days before harvest.

Methyl parathion within 15 days before harvest.

Phosphamidon within 21 days before harvest.

Dieldrin within 30 days before harvest.

Do not apply DDT to rice after heads start to form.

Do not feed rice straw to dairy animals or animals being finished for slaughter if the rice straw has been treated with DDT, phosphamidon, or toxaphene.

Do not feed rice straw to livestock if the rice straw was treated with aldrin within 30 days of harvest or with dieldrin within 20 days of harvest.

² Sevin should not be applied to rice that has been or will be treated with DPA herbicide.

Selected References

- (1) ATKINS, J. G., NEWSOM, L. D., SPINK, W. T., and others.
1960. OCCURRENCE OF HOJA BLANCA AND ITS INSECT VECTOR, *SOGLATA ORIZICOLA* MUIR, ON RICE IN LOUISIANA. *Plant Dis. Rptr.* 44: 390-393.
- (2) BOWLING, C. C.
1960. CONTROL OF RICE STINKBUGS AND GRASSHOPPERS ON RICE. *Tex. Agr. Expt. Sta. Prog. Rpt.* 2132, 6 pp.
- (3) DOUGLAS, W. A., and INGRAM, J. W.
1942. RICE FIELD INSECTS. U.S. Dept. Agr. Cir. 632, 32 pp.
- (4) ——— and TULLIS, E. C.
1950. INSECTS AND FUNGI AS CAUSES OF PECKY RICE. U.S. Dept. Agr. Tech. Bul. 1015, 20 pp.
- (5) GRIGARICK, A. A., LANGE, W. H., and FINFROCK, D. C.
1961. CONTROL OF THE TADPOLE SHRIMP, *TRIOPS LONGICAUDATUS*, IN CALIFORNIA RICE FIELDS. *Jour. Econ. Ent.* 54: 36-40.
- (6) ISELY, DWIGHT, and SCHWARDT, H. H.
1934. THE RICE WATER WEEVIL. *Ark. Agr. Expt. Sta. Bul.* 299, 44 pp.
- (7) LANGE, W. H., JR., INGEBRETSEN, K. H., and DAVIS, L. L.
1953. RICE LEAF MINER. *Calif. Agr.* 7(8): 8-9.
- (8) PORTMAN, R. F., and WILLIAMS, A. H.
1952. CONTROL OF MOSQUITO LARVAE AND OTHER PESTS IN RICE FIELDS BY DDT. *Jour. Econ. Ent.* 45: 712-716.
- (9) ROLSTON, L. H., and ROUSE, PHIL.
1960. CONTROL OF GRAPE COLASPIS AND RICE WATER WEEVIL BY SEED OR SOIL TREATMENT. *Ark. Agr. Expt. Sta. Bul.* 624, 10 pp.
- (10) ROSENBERG, L. E.
1947. APUS AS A PEST IN CALIFORNIA RICE FIELDS. *Calif. Dept. Agr. Bul.* 36(2): 42-48.