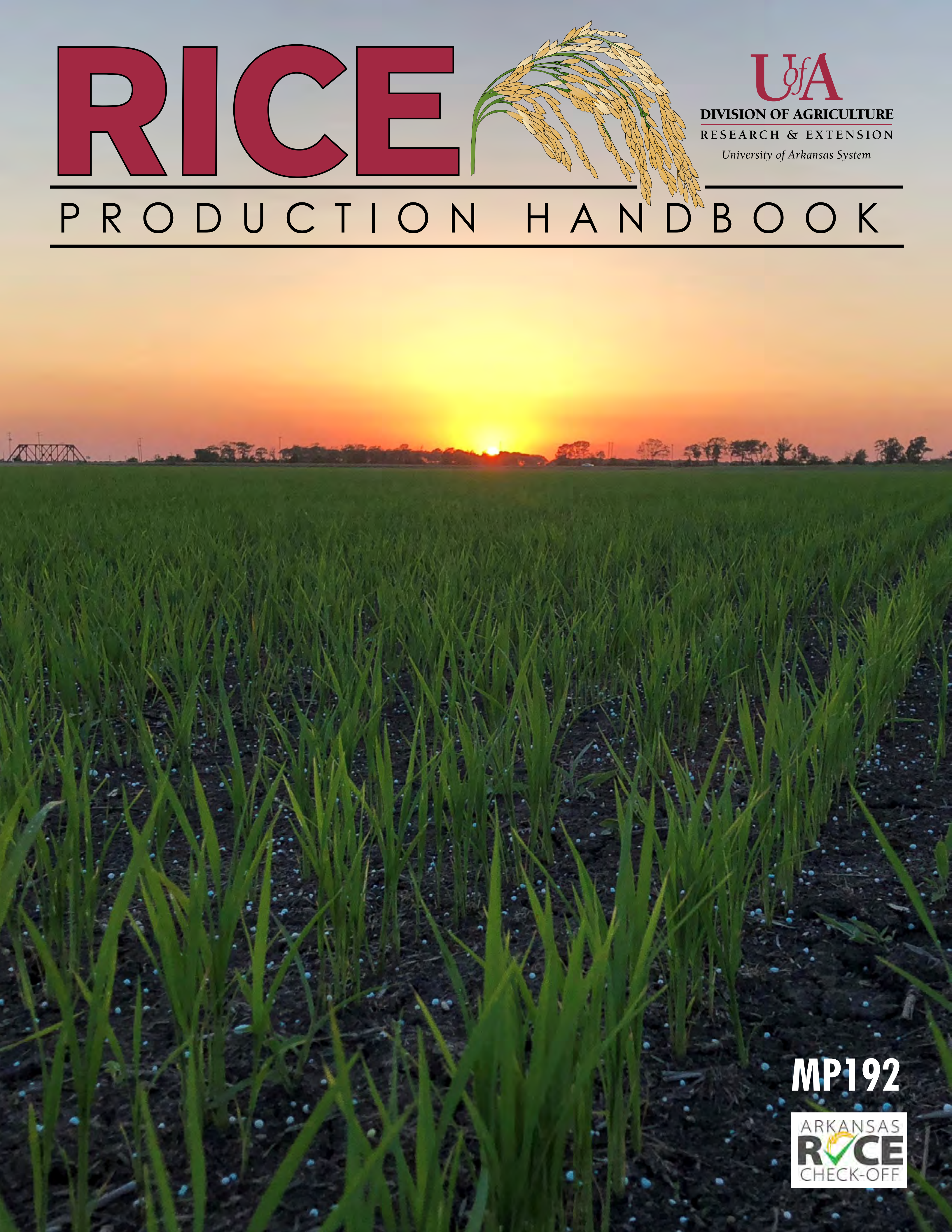
RICE
PRODUCTION HANDBOOK

U of A
DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System



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ARKANSAS RICE CHECK-OFF

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1

Introduction

Jarrod Hardke

Rice production reportedly began in Arkansas in 1902 with one acre of rice grown in Lonoke County. However, some historical records suggest that rice was grown in some parts of Arkansas prior to the Civil War. Official state records for rice production have been kept since 1905 for yields, harvested acres and prices (Table 1-1). Rice acreage gradually increased until 1955 when the first government acreage controls stabilized rice production on about 500,000 acres. Marketing quotas were lifted in 1974 and rice acreage increased, reaching a peak in 1981 at 1.54 million harvested acres, which was not surpassed until 1999. In 2010, Arkansas rice producers planted and harvested a record of 1.791 and 1.785 million acres, respectively. Currently, rice is grown in 40 of the state's 75 counties and ranks as one of the top three crop commodities in cash receipts for Arkansas farmers.

The Arkansas rice-producing area is primarily in the eastern one-half of the state (Figure 1-1). Rice is also produced in the Arkansas River Valley and in the Ouachita and Red River valleys in southwest Arkansas. The state latitude range is from about 33° N where Arkansas borders Louisiana in the south to 36° 30' N along the northern border shared with Missouri. The state longitude ranges from 89° 36' W where Arkansas borders Tennessee and Mississippi to the east to 94° 36' W along the western border shared with Oklahoma and Texas.

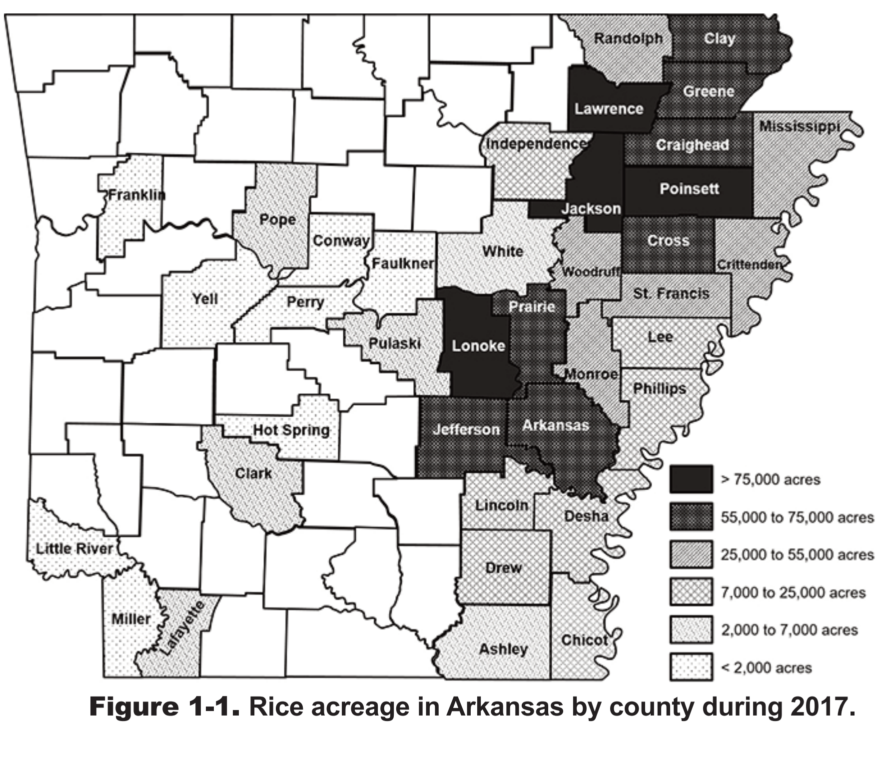


Figure 1-1. Rice acreage in Arkansas by county during 2017.

Table 1-1. **History of Arkansas rice acreage and state average yield**[†]**.**

Year	Harvested Acres (1,000)	Yield (bu/A)	Average Price ($/cwt)	Year	Harvested Acres (1,000)	Yield (bu/A)	Average Price ($/cwt)	Year	Harvested Acres (1,000)	Yield (bu/A)	Average Price ($/cwt)
1905	1	32.0	2.25	1943	257	47.0	3.80	1981	1540	100.4	9.37
1906	4	38.0	1.89	1944	287	52.5	3.87	1982	1330	95.3	8.61
1907	6	37.5	1.89	1945	281	47.0	3.84	1983	915	95.1	9.18
1908	11	42.6	2.04	1946	320	44.5	5.04	1984	1150	102.2	8.51
1909	27	46.8	1.93	1947	365	46.6	5.78	1985	1050	**115.6**	6.70
1910	60	45.0	1.51	1948	391	52.4	4.64	1986	1020	**117.8**	3.68
1911	72	44.0	1.80	1949	412	47.8	4.07	1987	1010	116.7	7.60
1912	91	43.5	1.98	1950	346	50.0	5.13	1988	1210	**118.9**	6.90
1913	105	42.0	2.04	1951	457	44.4	4.98	1989	1140	**124.4**	7.46
1914	93	42.5	1.91	1952	466	45.6	5.82	1990	1200	111.1	6.75
1915	100	46.0	1.89	1953	494	51.1	4.93	1991	1260	117.8	7.69
1916	125	50.5	2.20	1954	672	55.6	4.25	1992	1380	122.2	5.93
1917	152	45.5	4.20	1955	434	69.4	5.00	1993	1230	112.2	7.97
1918	170	42.0	3.51	1956	382	71.1	4.93	1994	1420	**126.7**	6.52
1919	160	47.5	4.93	1957	332	68.9	5.16	1995	1340	121.1	9.14
1920	180	49.0	2.38	1958	336	65.6	4.94	1996	1170	**136.7**	10.20
1921	140	53.5	2.00	1959	383	75.6	4.60	1997	1390	126.7	9.87
1922	163	48.0	1.98	1960	384	78.3	4.41	1998	1485	128.9	8.87
1923	143	39.5	2.29	1961	384	77.8	5.20	1999	1625	130.0	5.71
1924	166	43.0	2.78	1962	426	85.6	5.10	2000	1410	135.8	5.60
1925	176	43.0	3.16	1963	426	95.6	4.92	2001	1621	**141.1**	3.93
1926	196	52.8	2.29	1964	430	95.6	4.87	2002	1503	**143.1**	4.16
1927	179	43.0	1.91	1965	434	95.6	4.98	2003	1455	**146.9**	7.70
1928	173	47.9	1.89	1966	477	95.6	5.09	2004	1555	**155.1**	7.13
1929	156	51.0	2.11	1967	477	101.1	5.12	2005	1635	147.8	7.27
1930	173	47.5	1.76	1968	572	95.6	5.07	2006	1400	153.3	9.43
1931	177	55.0	0.98	1969	515	105.6	5.32	2007	1325	**160.7**	12.10
1932	163	51.0	0.84	1970	438	106.7	5.41	2008	1395	148.0	15.00
1933	147	49.0	1.78	1971	441	112.2	5.62	2009	1470	151.1	13.40
1934	141	47.2	1.82	1972	441	110.6	7.20	2010	1785	144.0	11.30
1935	138	44.0	1.82	1973	533	106.0	15.30	2011	1154	150.4	13.40
1936	160	54.7	1.82	1974	710	102.4	11.40	2012	1285	**166.2**	14.30
1937	189	56.0	1.33	1975	898	100.9	8.54	2013	1070	**168.0**	15.20
1938	189	51.4	1.38	1976	847	106.0	7.25	2014	1480	168.0	12.00
1939	171	50.0	1.67	1977	837	94.0	9.79	2015	1291	163.1	10.90
1940	191	50.2	1.80	1978	1090	98.9	8.47	2016	1521	153.8	9.39
1941	212	51.5	2.73	1979	1020	96.0	10.60	2017	1111	166.4	11.50
1942	265	48.0	3.56	1980	1280	91.3	12.30				

[†]Information obtained from National Agricultural Statistics Service, United States Department of Agriculture.

Approximately 50, 44 and 6 percent of the rice grown in Arkansas is produced on silt loam, clay and sandy loam soils, respectively. About 85 percent of the rice is drill seeded and 15 percent is broadcast seeded (10 percent broadcast dry seeded; 5 percent broadcast water seeded).

Arkansas produces approximately 48 percent of U.S. rice and ranks number one in acres planted and bushels produced. Arkansas has been the nation's leading rice-producing state since 1973. Other major rice-producing states include California, Louisiana, Texas, Mississippi and Missouri. Prior to 1973, no one state dominated rice production. Arkansas, California, Louisiana and Texas each accounted for near equal proportions of rice production in the U.S.

Rice planting typically begins during the last week of March and continues into early June. Planting is approximately 50 and 95 percent completed by April 24 and June 1, respectively (Figure 1-2). Since most of Arkansas' rice is produced with a drilled dry-seeded culture, flooding of rice fields typically begins at the end of May and early June when the rice reaches the 4- to 5-leaf growth stage.

Rice harvest normally begins during the middle of August and concludes toward the end of October or early November (Figure 1-3). Planting progress statistics suggest that rice planting progress has not changed appreciably over the last 30 years. The five-year averages for rice planting progress by April 15 for the years 1969-1973 and 2011-2015 indicate that 24 and 31 percent of the rice acreage was planted, respectively. However, the five-year averages for rice harvesting progress by September 20 for the years 1969-1973 and 2005-2009 indicate that 16 and 52 percent of rice acreage was harvested, respectively. Improvements in harvest efficiency and the development of new shorter-season rice cultivars during the past 20 years are primarily responsible for earlier harvest.

In Arkansas, rice yields have increased dramatically since the early 1980s. Prior to 1985, Arkansas' highest average yield was 112 bushels per acre in 1971. Since 1985, the state average yield record has been broken 11 times, including four consecutive years between 2001 and 2004. The current record of 68 bushels per acre (45 pounds rough rice per bushel) was set in 2013 and tied in 2014. The highest county average yield is 181.3 bushels per acre produced by rice growers in Mississippi County in 2014. The common range for rough rice yields in Arkansas commercial rice fields is 150 to 200 bushels per acre at 12 percent moisture.

Poinsett, Lawrence and Arkansas counties are the three largest rice-producing counties in the state and rank among the top five counties in the nation in acres planted and bushels produced. Over the past 10 years, 2008 to 2017, Poinsett County has averaged more than 100,000 harvested acres of rice. Lawrence, Arkansas, Jackson, Cross and Lonoke counties rank next in number of harvested acres.

The history of rice production in Arkansas reveals four recent phases when yields increased dramatically over a two- to three-year period (Table 1-1). Each phase coincides with the release, subsequent acceptance and adoption and widespread growth of a new cultivar or cultivars (Tables 1-2a-e). Tables 1-2a through 1-2e show the cultivar distribution of Arkansas rice acreage from 1964 to 2015.

The first phase of noticeable increase in rice yield occurred following the 1967 release of Starbonnet by the University of Arkansas Division of Agriculture. Prior to 1967, the highest average rice yield was 96 bushels per acre. Widespread adoption of Starbonnet led to record yields from 1969-1971 (Table 1-1). Starbonnet replaced Bluebonnet as the most popular rice cultivar beginning in 1969 and remained the number one cultivar through 1984, during which time yields remained near or above 100 bushels per acre (Tables 1-2c, 1-2d and 1-2e). Newbonnet and Lemont were released in 1983 and 1985, respectively. State average rice yields increased an additional 10 bushels per acre when in 1985 Newbonnet replaced Starbonnet as the most widely grown cultivar. In 1984, Starbonnet, Lebonnet and Labelle were planted on 80.7 percent of the state's acres. In 1985, these three cultivars were planted on less than 13 percent of the state's acreage. In comparison,

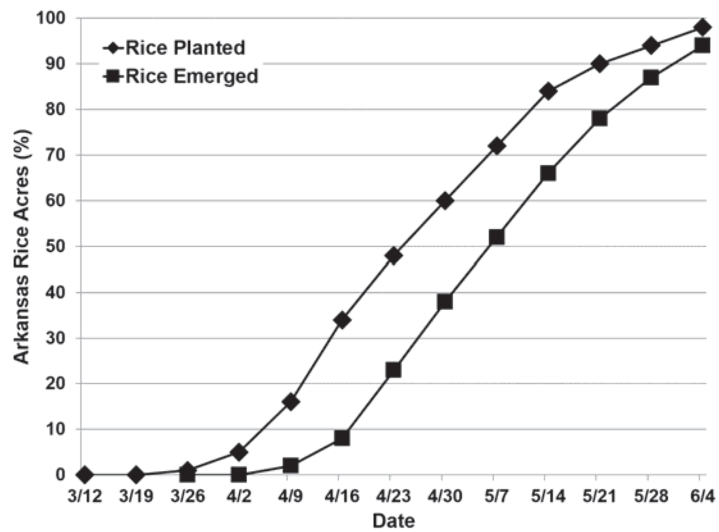


Figure 1-2. Average planting and emergence progress 7or Arkansas rice acreage from 2013 to 2017.

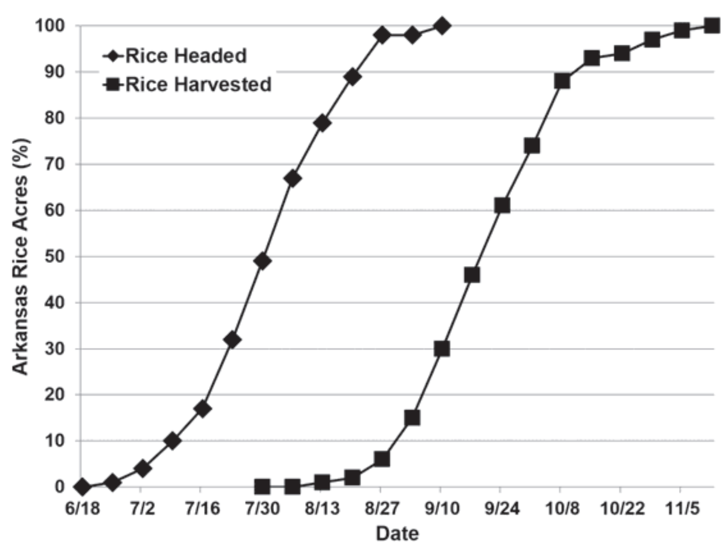


Figure 1-3. Average harvest progress for Arkansas rice acreage between 2013 and 2017.

Table 1-2a. **Distribution of rice varieties produced in Arkansas between 2008 and 2017†.**

Varieties	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
	% of Total Acres									
AB647	0.3	0.4	0.3	0.6	<0.1	-	0.2	0.3	-	-
Antonio	<0.1	<0.1	0.3	0.2	<0.1	-	-	-	-	-
Bengal	0.1	-	-	-	-	-	-	0.4	1.9	1
Caffey	0.2	<0.1	0.3	0.2	0.2	-	-	-	-	-
Catahoula	<0.1	-	-	-	-	0.1	0.2	0.5	-	-
Cheniere	1.1	0.9	0.2	1.2	1.9	2.1	2.1	8.9	5.4	2.1
CL111	1.6	1.6	3.8	5	6	4.1	3	1.3	-	-
CL131	-	-	-	-	<0.1	0.2	0.8	2.9	3.7	0.3
CL142 AR	-	-	-	0.5	0.7	1.8	7.5	0.6	-	-
CL151	6.8	13.2	12.4	12.6	9.7	13.1	12.4	22.5	11.8	<0.1
CL152	-	<0.1	0.4	3.3	7.8	-	-	-	-	-
CL153	8.9	<0.1	-	-	-	-	-	-	-	-
CL161	-	-	-	-	<0.1	0.3	0.2	0.2	0.7	5.3
CL163	0.5	0.9	0.1	-	-	-	-	-	-	-
CL171 AR	-	-	-	-	-	-	0.2	0.5	6.4	13.8
CL172	3.6	0.2	-	-	-	-	-	-	-	-
CL181 AR	-	-	-	-	-	-	1.7	0.4	-	-
CL261	-	-	-	0.6	0.7	1.1	5.8	-	-	-
CL271	-	1.4	3.4	-	-	-	-	-	-	-
CL272	0.6	<0.1	-	-	-	-	-	-	-	-
Cocodrie	-	-	<0.1	<0.1	0.1	0.6	-	0.8	1.9	5.2
Cybonnet	-	-	-	-	-	-	-	-	0.2	1.2
Della-2	0.1	0.1	-	<0.1	<0.1	-	-	-	-	-
Dellrose	-	-	-	-	0.3	0.1	0.1	-	-	-
Diamond	8.6	0.2	-	-	-	-	-	-	-	-
Francis	0.9	0.5	0.7	1.3	1.9	3.7	1.7	6	9.6	11.8
Jazzman	<0.1	-	-	0.1	0.4	0.1	<0.1	-	-	-
Jazzman-2	0.3	0.3	0.2	<0.1	<0.1	-	-	-	-	-
Jupiter	8.9	6.3	14.4	13	9.9	7.6	13.4	8.7	12.5	6.2
LaKast	2.6	7.9	5	0.2	-	-	-	-	-	-
Mermentau	0.4	1.6	4.1	4.9	1	-	-	-	-	-
Neptune	-	-	-	-	-	-	1.2	1.5	0.8	<0.1
Rex	0.3	<0.1	-	-	<0.1	-	-	-	-	-
RT 7311 CL	1	-	-	-	-	-	-	-	-	-
RT CLXL8	-	-	-	-	-	0.3	<0.1	-	-	0.2
RT CLXL729	2.8	3.6	3.2	4.2	7.4	11.4	7	6.5	15.1	14.7
RT CLXL730	-	-	-	-	-	-	-	-	0.9	9.4
RT CLXL745	18.6	22.3	19.9	22	22.3	28.4	29.4	19.5	8.1	1.9
RT CLXL746	-	-	0.3	0.2	0.2	0.4	0.4	0.6	-	-
RT CLXL756	1.1	1.6	-	-	-	-	-	-	-	-
RT Gemini 214 CL	0.7	-	-	-	-	-	-	-	-	-
RT XL723	0.2	0.6	0.9	1.1	3.4	9.8	3.1	1.5	2.7	1.1
RT XP753	16.5	15.2	14.5	11.8	6.2	-	-	-	-	-
RT XL760	1.3	0.2	-	-	-	-	-	-	-	-
RT XP754	0.6	0.3	-	-	-	-	-	-	-	-
Roy J	5.8	18.2	13.1	12.6	13.8	6.3	2.1	0.1	-	-
Spring	<0.1	<0.1	-	-	-	-	-	-	<0.1	<0.1
Taggart	0.9	0.6	0.5	1.2	1	2.1	0.7	0.5	-	-
Templeton	-	-	-	-	-	-	0.2	0.6	-	-
Titan	3.0	<0.1	-	-	-	-	-	-	-	-
Trenasse	-	-	-	-	-	-	-	-	<0.1	0.2
Wells	1.5	0.9	1.6	2.9	3.1	6.1	6.5	15	16.5	25.1

†Variety distribution data obtained from DD50 computer program.

Newbonnet and Lemont acreage increased from 6.5 percent in 1984 to almost 77 percent in 1985. During the 1990s, average rice yields increased an additional 10 bushels per acre as the number of available cultivars increased considerably. Cultivars such as Bengal, Cypress and Kaybonnet dominated rice acreage during this time (Table 1-2b). A new era of rice cultivars and new yield records were realized during the first part of the 21st century. In 1999, Wells and Cocodrie were released and rapidly

Table 1-2b. Distribution of rice varieties produced in Arkansas between 1998 and 2007†.

Varieties	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998
	% of Total Acres									
Ahrent	<0.1	<0.1	0.3	0.9	2.3	2.5	0.1	-	-	-
Alan	-	-	-	-	-	-	-	-	0.6	0.9
Banks	0.3	0.9	3.6	0.2	-	-	-	-	-	-
Bengal	7.5	6.2	4.8	9.9	11.2	9.3	9.1	20	17.1	13.6
Cheniere	-	10.6	6.6	1.2	-	-	-	-	-	-
CL121	-	-	0.1	0.5	0.3	1.2	-	-	-	-
CL131	-	13.1	0.1	-	-	-	-	-	-	-
CL141	-	-	-	-	-	0.7	-	-	-	-
CL161	10.2	6.7	18.2	13.2	4.7	0.3	-	-	-	-
CL171 AR	1	-	-	-	-	-	-	-	-	-
Cocodrie	6.5	4.4	9.1	15.3	21.8	29.3	30.1	16.4	0.8	-
Cybonnet	3.7	1.7	1.1	0.1	-	-	-	-	-	-
Cypress	<0.1	<0.1	0.2	1.3	1.6	3.9	8.6	15	21.9	25.6
Drew	-	<0.1	0.2	0.7	0.9	4.5	13	27.2	35.1	37
Francis	11	9.6	10.7	11.3	6.3	0.3	-	-	-	-
Jackson	-	-	-	-	-	-	-	-	0.1	0.2
Jefferson	-	<0.1	0.1	0.1	0.3	0.2	0.3	0.3	5.8	1.8
Jupiter	3.4	<0.1	-	-	-	-	-	-	-	-
Kaybonnet	-	-	-	-	-	0.1	0.9	2.4	4.9	8.4
LaGrue	-	-	0.1	0.8	2.6	3.4	5.8	10.4	9.9	10.2
Lemont	-	-	-	-	-	0.2	0.3	0.4	2.8	1.7
Madison	-	-	-	-	-	-	-	-	0.1	-
Mars	-	-	-	-	-	-	-	-	0.2	-
Medark	-	0.3	1.5	0.1	-	-	-	-	-	-
Millie	-	-	-	-	-	-	-	-	-	0.2
Newbonnet	-	-	-	-	-	-	-	-	-	0.2
Priscilla	-	-	-	-	-	0.1	-	-	0.3	-
RT CLXL8	2.2	5.6	2.5	2.5	-	-	-	-	-	-
RT CLXL729	5.2	<0.1	-	-	-	-	-	-	-	-
RT CLXL730	4.1	4.8	<0.1	-	-	-	-	-	-	-
RT XL6	-	-	-	-	-	0.8	-	-	-	-
RT XL8	-	-	0.4	1.4	1.1	-	-	-	-	-
RT XP710	-	1.1	0.7	0.1	<0.1	-	-	-	-	-
RT XP716	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-
RT XL723	8.5	1.9	0.7	<0.1	-	-	-	-	-	-
Saber	-	-	-	-	0.2	0.2	-	-	-	-
Spring	0.1	0.1	<0.1	-	-	-	-	-	-	-
Trenasse	0.2	<0.1	<0.1	-	-	-	-	-	-	-
Wells	35.5	31	38.9	39.8	45.2	41.6	30.1	4	0.2	-

†Variety distribution data obtained from DD50 computer program.

increased to account for the majority of the total acreage (Tables 1-2a and 1-2b). After the release of those cultivars, record yields were achieved each year between 2001 and 2004.

New technology has begun to again raise the bar for rice yields in Arkansas. The first hybrid rice cultivars were released in 2002-2003. These cultivars exhibited excellent yield potential and showed the ability to increase production but were initially limited by seed production. As of 2017, hybrid cultivars represent over 40 percent of rice acres. Clearfield rice, which has been bred through traditional techniques to be tolerant to imidazilanone and imazamox herbicides, was first planted on limited acreage in 2002. The expansion of this technology has had a positive impact by allowing red rice-infested acres to be unaffected by the yield and quality-limiting effects of this weed.

From 1967 to 1985, rice acreage in Arkansas increased from 0.5 million acres to over 1 million acres (Table 1-1). This increase in rice acreage likely resulted in lower yields during the late 1970s and early 1980s as a result of both marginal land being placed in production and producers adjusting to the difficulties inherent in managing additional acres. In addition to the availability of improved cultivars, other events have significantly impacted Arkansas rice

Table 1-2c. **Distribution of rice varieties produced in Arkansas between 1987 and 1997[†].**

Variety	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988	1987
	% of Total Acres										
Adair	-	0.2	0.4	-	-	-	-	-	-	-	-
Alan	2.4	3.4	9.2	17.4	28.5	19.4	3.8	0.2	-	-	-
Bengal	18.2	22	13.6	7.1	-	-	-	-	-	-	-
Bond	-	-	-	-	-	-	-	-	-	-	0.2
Cypress	28.8	27	34.9	0.1	-	-	-	-	-	-	-
Drew	3	0.1	-	-	-	-	-	-	-	-	-
Gulfmont	-	-	-	-	-	-	-	2.3	2.9	1.8	0.2
Jackson	0.2	0.6	1.1	1.6	-	-	-	-	-	-	-
Jefferson	0.1	-	-	-	-	-	-	-	-	-	-
Katy	0.1	0.4	8.6	11.9	18.8	20.8	12.5	5.5	0.3	-	-
Kaybonnet	33.8	33.4	4.3	0.1	-	-	-	-	-	-	-
L202	-	-	-	-	-	-	-	2.2	0.9	0.9	0.9
Labelle	-	-	-	-	-	-	-	0.7	1.1	0.7	0.9
Lacassine	0.2	0.8	2.9	4	-	-	-	-	-	-	-
LaGrue	9.8	7	11.6	1.6	-	-	-	-	-	-	-
Lebonnet	-	-	-	-	-	-	-	0.2	0.6	1.1	1.3
Lemont	1.7	2.3	4.2	10.1	12.1	15.8	15.3	20.5	23.4	27.7	16.7
Mars	-	0.1	1.1	5.5	6	7.1	11.8	10.8	8.7	9.4	10.8
Maybelle	-	-	-	-	-	-	-	0.6	-	-	-
Millie	0.7	0.1	2.8	6	7.9	8.3	2.2	0.1	-	-	-
Newbonnet	0.6	1.3	4.1	10.4	8.8	19.3	38.3	39.5	44.5	32.6	54.5
Newrex	-	-	-	-	-	-	-	-	-	-	0.4
Nortai	-	-	-	-	-	-	-	-	-	-	0.3
Orion	-	-	0.1	1.6	5.9	1.2		-	-	-	-
Rexmont	-	-	-	-	-	-	-	0.4	0.4	0.4	0.1
Skybonnet	-	-	-	-	-	-	-	0.4	0.5	0.8	0.3
Starbonnet	-	-	-	-	-	-	-	-	-	-	0.2
Tebonnet	-	-	-	-	-	-	-	16.4	16.3	24.1	13.2

[†]Variety distribution data obtained from DD50 computer program beginning in 1981 and from Rice Millers Association Report prior to 1981.

production over the past 50 years. In 1975, 53 rice growers in 11 counties field tested an alternate method of timing mid-season nitrogen fertilizer applications. In 1978, the program became available to all farmers in Arkansas. The program, now known as the computerized DD50 program, helps farmers with 29 management decisions and is used on 30 percent or more of the state's acreage.

Other important events and dates in Arkansas rice production are listed below:

- 1961 – Propanil first used in commercial rice fields
- 1968 – Molinate first used in commercial rice fields
- 1975 – DD50 Program implemented
- 1982 – Collego labeled to control northern jointvetch
- 1987 – Discovery of poultry litter to reclaim precision-graded silt loam soils
- 1989 – Katy released as blast-tolerant variety
- 1990 – Gibberellic acid seed treatment received label
- 1990 – Propanil-resistant barnyardgrass documented
- 1991 – Sheath blight treatment thresholds changed to account for cultivar tolerance
- 1992 – Facet labeled for weed control in rice
- 1997 – Quadris, first strobilurin-type fungicide, labeled for rice
- 1998 – Dale Bumpers National Germplasm Center completed
- 1999 – Facet-resistant barnyardgrass documented
- 2000 – Command labeled for weed control in rice
- 2001 – Clearfield rice introduced into Arkansas for red rice control
- 2002 – Hybrid rice introduced into Arkansas
- 2003 – First recommendation to amend preflood urea with an NBPT-containing urease inhibitor
- 2004 – Newpath-tolerant red rice first documented in Arkansas
- 2006 – Liberty-Link rice, a genetically modified rice, was detected in the U.S. commercial rice supplies

Table 1-2d. Distribution of rice varieties produced in Arkansas between 1975 and 1985†.

Variety	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977	1976
	% of Total Acres										
Bluebelle	-	-	-	-	-	-	-	-	-	1.6	5.2
Bond	0.8	5.6	3.6	0.3	-	-	-	-	-	-	-
Bonnet 73	-	-	-	-	-	-	-	-	-	1.2	2.6
Brazos	-	-	-	-	-	-	-	-	-	2.8	1.8
Dawn	-	-	-	-	-	-	-	-	-	0.1	1.2
Labelle	0.7	4.1	18.8	25.2	20.4	17.2	17.3	14.6	11.4	7.3	7.6
Lebonnet	1.2	5.5	20.1	20.6	14.9	15.5	25.1	30	30	33.9	22.9
Lemont	11.4	12.2	1.4	-	-	-	-	-	-	-	-
Mars	6.9	4.3	7.4	11.1	11.4	14.5	10.8	2.4	0.1	-	-
Nato	-	-	-	-	-	-	-	-	-	10.3	13.2
Newbonnet	68.9	61.2	5.1	0.3	-	-	-	-	-	-	-
Newrex	0.3	0.3	0.6	0.3	-	-	-	-	-	-	-
Nortai	0.1	0.1	0.1	0.3	0.9	0.9	1.6	1.7	1.7	2.2	2
Nova	-	-	-	-	-	-	-	-	-	2.1	3.3
Saturn	-	-	-	-	-	-	-	-	-	0.1	0.2
Starbonnet	0.5	2.9	41.8	41.7	52.4	50.4	40.2	43.9	38.1	38.3	39.5
Tebonnet	9.2	3.2	-	-	-	-	-	-	-	-	-
Vista	-	-	-	-	-	-	-	-	-	0.2	0.7

†Variety distribution data obtained from Rice Millers Association Report.

Table 1-2e. Distribution of rice varieties produced in Arkansas between 1964 and 1975†.

Variety	1975	1974‡	1973	1972	1971	1970	1969	1968	1967	1966	1965	1964
	% of Total Acres											
Arkrose	-	n/a	-	-	-	-	-	-	-	-	0.8	1.1
Belle Patna	-	n/a	1.4	0.5	0.6	1	1.9	2.8	5	5.5	1.8	1.1
Bluebelle	7.4	n/a	9.6	3.9	4	7.3	9.3	23.1	5.6	0.2	-	-
Bluebonnet	0.7	n/a	0.1	1.7	2	5.6	12	27.4	50.6	50.9	54.2	53.7
Bonnet 73	5.2	n/a	-	-	-	-	-	-	-	-	-	-
Brazos	1.7	n/a	-	-	-	-	-	-	-	-	-	-
Century Patna	-	n/a	-	-	-	-	-	0.1	0.5	0.9	0.9	0.9
Dawn	3.4	n/a	0.8	0.6	0.6	0.9	2	2.3	0.8	0.1	-	-
Labelle	7.6	n/a	0.3	-	-	-	-	-	-	-	-	-
Lebonnet	1.4	n/a	-	-	-	-	-	-	-	-	-	-
Nato	15.2	n/a	20.4	19.9	18.4	16.1	17.6	22.2	31.1	37	39.3	37.6
Nortai	2.4	n/a	0.9	-	-	-	-	-	-	-	-	-
Northrose	-	n/a	-	-	-	-	-	-	-	-	0.3	0.9
Nova	2.9	n/a	5.5	5.6	5	6	6.8	4.2	2.4	1.9	1.2	3.6
Pearl	-	n/a	0.1	0.7	0.8	1	1.4	0.8	0.8	0.8	1.3	0.7
Roses	-	n/a	-	0.4	0.4	0.6	0.5	0.7	0.7	1	-	-
Saturn	0.3	n/a	1.2	0.3	0.6	1.3	1.5	0.8	0.3	0.2	-	-
Starbonnet	52.1	n/a	58.6	66.4	67.6	60.4	46.9	15.4	0.1	-	-	-
Vegold	-	n/a	-	-	-	-	0.3	0.2	1.2	1.5	0.2	0.3
Vista	0.4	n/a	0.5	-	-	-	-	-	-	-	-	-
Zenith	-	n/a	-	-	-	-	-	-	-	-	-	0.1

†Variety distribution data obtained from Rice Millers Association Report.
‡Data not available for 1974.

- 2008 – Command-resistant barnyardgrass documented
- 2009 – ALS-resistant barnyardgrass documented
- 2010 – New Rice Research and Extension Center office and laboratory facility opened
- 2012 – Nitrogen Soil Test for Rice (N-STaR) implemented to provide field-specific prescription nitrogen recommendations

The goal of the University of Arkansas Division of Agriculture is to assist farmers in producing profitable, high-yielding crops that enable our growers to be competitive on the world market. The Cooperative Extension Service is proud to present a summary of research-based recommendations and an overview of Arkansas rice production in this handbook. The presentation and publication of information in this handbook was made possible through cooperative efforts of the University of Arkansas Division of Agriculture and the Arkansas rice growers through grower check-off contributions which are administered by the Arkansas Rice Research and Promotion Board.

Links to Other Sources of U.S. Rice Production Information

University of Arkansas

Cooperative Extension Service, University of Arkansas – http://www.uaex.edu/rice

Arkansas Variety Testing – http://www.arkansasvarietytesting.com

B.R. Wells Rice Research Series – http://arkansas-ag-news.uark.edu/research-series.aspx

Other States

Louisiana State University – http://www.lsuagcenter.com/topics/crops/rice

Mississippi State University – http://extension.msstate.edu/agriculture/crops/rice

Texas A&M University – http://beaumont.tamu.edu

University of California-Extension Rice Project – http://ucanr.edu/sites/UCRiceProject/

University of Missouri – http://agebb.missouri.edu/murice/

Other Rice Links

National Ag Statistics Services (NASS) – http://www.nass.usda.gov/

Arkansas Rice Research and Promotion Board – http://www.arkrice.org/

Arkansas Farm Bureau Federation – http://www.arfb.com

Chapter 2

Rice Growth and Development

Karen Moldenhauer, Paul Counce and Jarrod Hardke

Rice is an annual grass (Figure 2-1) with round, hollow, jointed culms; narrow, flat, sessile leaf blades joined to the leaf sheaths with collars; well-defined, sickle-shaped, hairy auricles; small acute to acuminate or two cleft ligules (Figure 2-2); and terminal panicles. The life cycle of rice cultivars in Arkansas ranges from 105 to 145 days from germination to maturity, depending on the variety and the environment.

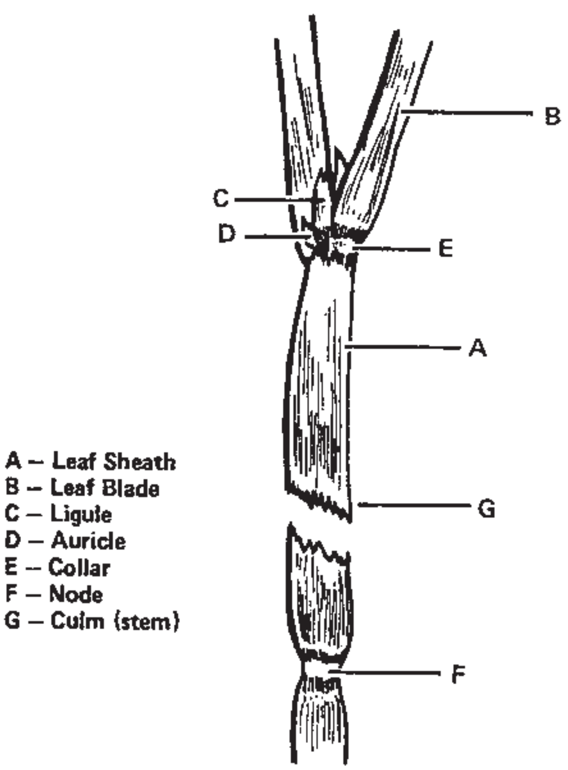


Figure 2-1. Leaf and culm morphology.

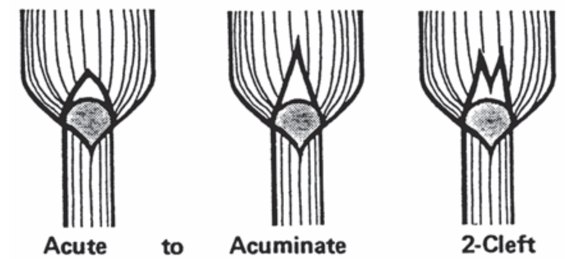


Figure 2-2. Ligule shapes of U.S. rice cultivars.

Management Key
Identification of plant parts is essential in differentiating rice plants from weeds.

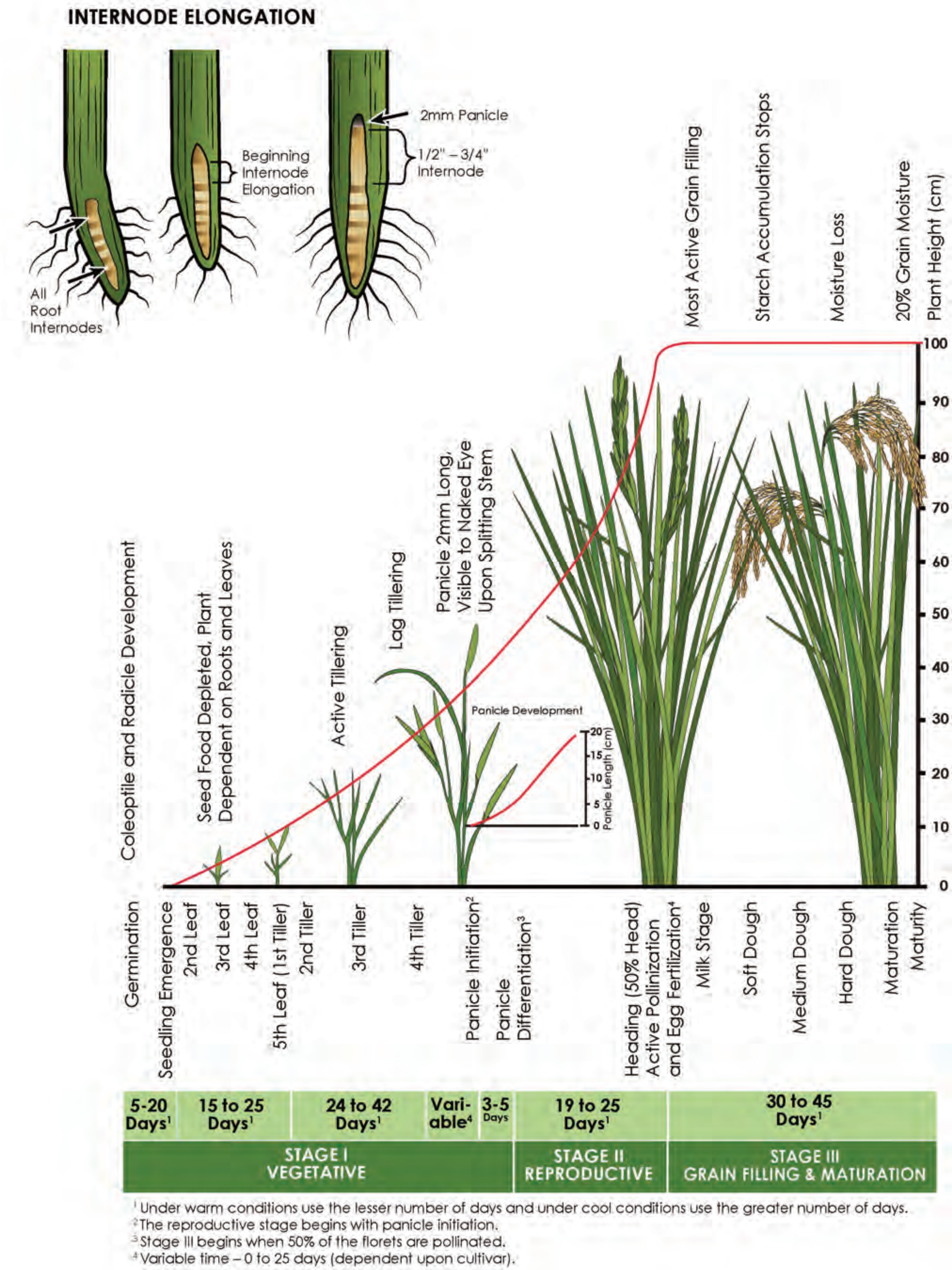
Rice plant growth can be divided into three agronomic phases of development (Figure 2-3):

1. Vegetative (germination to panicle initiation (PI));
2. Reproductive (PI to heading); and
3. Grain filling and ripening or maturation (heading to maturity).

These stages influence the three yield components: 1) number of panicles per unit land area, 2) the average number of grain produced per panicle and 3) the average weight of the individual grains. These three components determine grain yield.

The following descriptions and diagrams characterize the growth stages for rice plants.

Figure 2-3. Developmental stages of the rice plant.



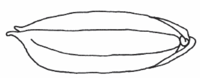
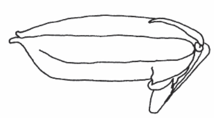
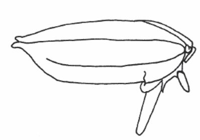
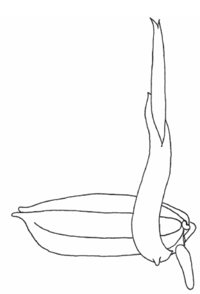
Vegetative Phase

The vegetative growth phase is characterized by active tillering, a gradual increase in plant height and leaf emergence at regular intervals. The length of this phase primarily determines the growth duration of cultivars. Some very-early-maturing cultivars have a shortened vegetative growth phase, while others have both shortened vegetative and reproductive growth phases. Panicle initiation (PI; R0 in the rice growth staging system) may occur before the maximum tiller number is reached in very-short-season and some short-season cultivars. Heading in these cultivars may be staggered due to later tillers which produce panicles. In midseason cultivars, the maximum tiller number is reached and followed by a vegetative lag phase before panicle initiation (PI) occurs.

The following distinct steps occur during the vegetative stage:

1. **Seed Germination** occurs when the seed coat has imbibed adequate water to become soft and elastic. The coleorhiza (the sheath covering the radicle or embryonic primary root) elongates slightly, emerging through the seed coat, allowing the radicle to break through the coleorhiza and become anchored in the soil. The coleoptile or primary leaf then elongates. Thus, under dry-seeded or aerobic conditions, the radicle emerges before the coleoptile. Under water-seeded or reduced oxygen (anaerobic) conditions, the coleoptile may emerge before the root (radicle or coleorhiza). This typically occurs within two days when temperatures are between 70° to 97°F. Below or above this temperature, germination requires more time. Germination occurs within the temperature range of 50° to 107°F with an optimum temperature of about 87°F. The rice growth staging system provides the terms S0, S1, S2 and S3 for the progressive stages of germination and seedling emergence (Figure 2-4).

Figure 2-4. Seedling growth stages.

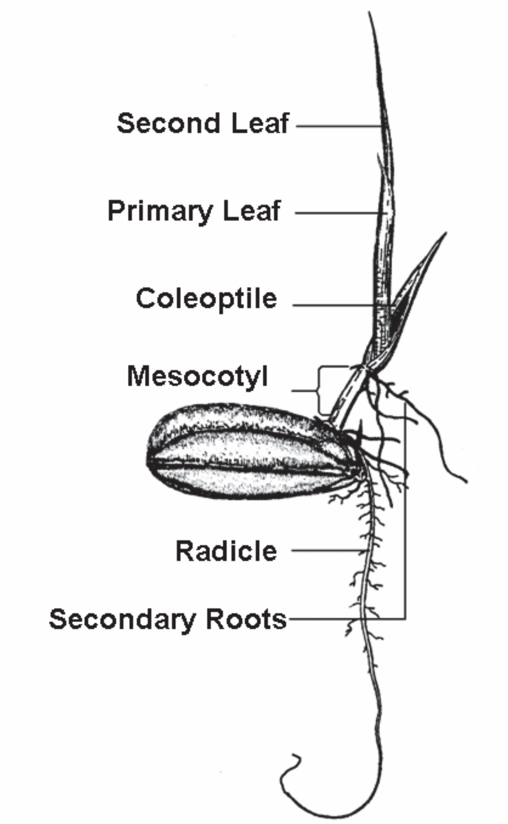
Seedling growth stages with morphological markers				
Growth Stage	SO	S1	S2	S3
Morphological Marker	Dry, unimbibed seed	Emergence of coleoptile	Emergence of radicle†	Emergence of prophyll from coleoptile††
Illustration				

† The sequence of normally occurring seedling developmental events is presented above. There are exceptions to the sequence of events. In some cases, the coleoptile emerges first; in other cases, the radicle emerges first. When either emerges alone, then the growth stage is S1. When both have emerged, the growth stage is S2. If the prophyll emerges from the coleoptile before the radicle emerges from the seed, then the growth stage is S3.

†† The prophyll is the first leaf to emerge, but it lacks a blade and a collar and consists only of the leaf sheath.

Nodal roots form at the coleoptile base and lateral roots form off the radicle (seminal root) (Figure 2-5). Subsequent roots form at each node.

Figure 2-5. **Parts of a germinating seedling.**

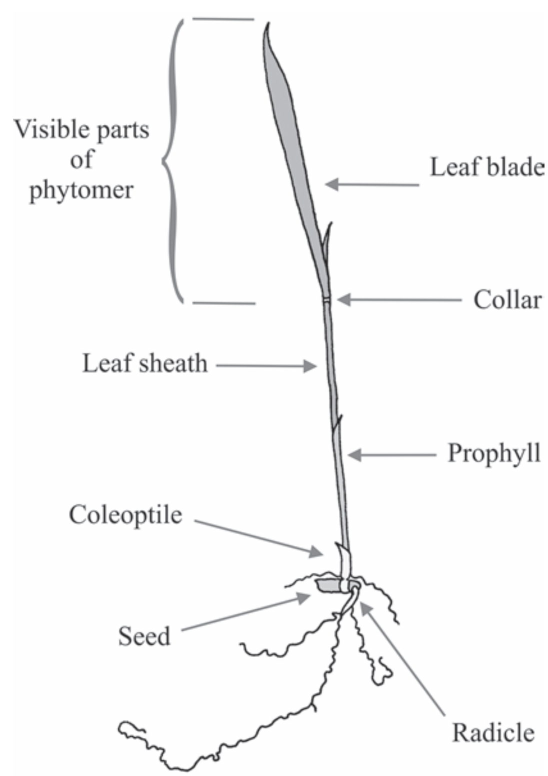


Management Key

(1) Imbibition of water by the seed is essential before application of the preemergence herbicides Prowl or Bolero to prevent injury. (2) There will be minimal seedling emergence from rice seed covered with both soil and water because of lack of O_2. (3) Higher seeding rates will not compensate for low temperatures or other adverse environmental conditions.

2. **Seedling Emergence** occurs when the first internode, called the mesocotyl, has elongated and pushed the tip of the rice coleoptile (epiblast) through the soil surface. The prophyll (first sheathing leaf) emerges through the coleoptile. It is not a true leaf because it lacks a leaf blade. The length of the mesocotyl varies with cultivars. Some semi-dwarf cultivars may have a very short mesocotyl and generally will not emerge if covered by more than ½ to ¾ inch of soil. The mesocotyl only develops in the dark and doesn't show up in water-seeded rice (Figure 2-5). The V1 growth stage (Figure 2-6) occurs when the first complete leaf pushes through the prophyll and forms a collar. At this point, the seedling has five roots formed from the coleoptilar node. The V2 growth stage occurs when the second leaf is fully emerged and progresses accordingly.

Figure 2-6. **Parts of a V1 rice plant.**



Management Key

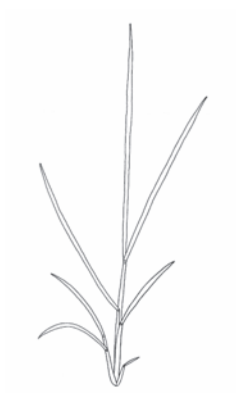
(1) Semi-dwarf cultivars with short mesocotyls may not emerge if covered with more than ½ to ¾ inch soil. When growing these cultivars, a gibberellic acid seed treatment (Release or GibGro) may be used to increase the mesocotyl length and, thus, emergence. (2) Emergence for starting the DD50 program is defined as the date when 10 of the rice coleoptiles per square foot have emerged above the soil surface. (3) Seedling germination and emergence typically vary from 5 to 28 days depending on the environment.

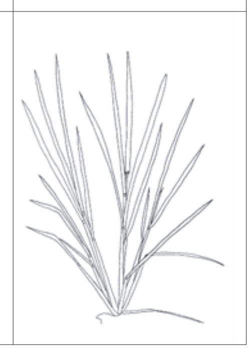
The complete set of V stages begin with the first complete leaf after the prophyll and end with collar formation on the final leaf (the “flag” leaf) on a culm (Figure 2-7).

3. **Pre-Tillering** – The period from the development of the first- to fourth-leaf stage (V1 – V4 stage) requires 15 to 25 days. During this time, the seminal root further develops, the secondary or lateral roots develop and the first four leaves appear (Figure 2-4). After seedling emergence, a new leaf emerges for every 100 to 175 accumulated DD50 units, normally every 3 to 7 days.

4. **Tillering** usually begins at the fifth-leaf stage (V5) when the first tiller is visible and emerges from the axillary bud of the second leaf on the culm. Tillering continues when the sixth leaf emerges and the second tiller comes from the

Figure 2-7. Vegetative growth stages.

Vegetative growth stages with morphological markers			
V5	**V6**	**V7**	**V8**
Collar formation on leaf 5 on main stem	Collar formation on leaf 6 on main stem	Collar formation on leaf 7 on main stem	Collar formation on leaf 8 on main stem
			

Vegetative growth stages				
V9 (VF-4)‡	**V10 (VF-3)‡**	**V11 (VF-2)‡**	**V12 (VF-1)‡**	**V13 (VF)‡**
Collar formation on leaf 9 on main stem	Collar formation on leaf 10 on main stem	Collar formation on leaf 11 on main stem	Collar formation on leaf 12 on main stem	Collar formation on leaf 13 on main stem
				

‡ Rice cultivars range from 10-20 leaves (V-stages) per main stem culm. This is an example for one with 13 leaves on the main stem.

axillary bud of the third leaf. Tillering continues in a synchronous manner with the nth leaf of the main culm and tiller emerging from the axillary bud of the (n-3)th leaf. During this period, the secondary roots grow down until flooding. Once flooded, these roots grow both vertically and laterally. The lateral growth is probably due to the availability of O_2, light and nutrients at the soil-water interface. During active tillering new leaves on the main culm emerge at a faster rate, requiring about 75 to 150 DD50 units or normally every 3 to 5 days.

Management Key

Tillering is necessary with low plant population (5 to 10 plants per square foot) and can be stimulated by extra preflood nitrogen during the rapid tillering stage as defined by the DD50 program.

5. **Maximum Tillering** – Tillering increases in a sigmoidal-shaped curve until the maximum tiller number is reached. At this point, the main culm may be difficult to distinguish from the tiller. In direct-seeded rice fields with a normal plant population (10 to 20 plants per square foot), rice plants generally produce two to five panicle-bearing tillers per plant compared to 10 to 30 tillers per plant in transplanted rice where more space is available between plants. After maximum tillering has occurred, no more effective tillers are produced. A portion of the late tillers will generally die due to competition effects. The first yield component, potential panicles per unit area, is determined at this time.

Management Key

Because of rapid growth during the active tillering stage, avoid using phenoxy herbicides (2,4-D) during this growth stage to prevent excessive injury.

6. **Vegetative Lag Phase** – The period from the end of active tillering to the beginning of the reproductive phase. Tiller number decreases; height and stem diameter continue to increase but at a slower rate. This is the time when phenoxy herbicides should be applied. The length of this period is a function of the maturation period of the cultivar. For very-short-season cultivars with 105-day maturity, this period may not be evident. In this situation, the maximum tillering stage and the beginning of reproductive growth may overlap. In a 145-day rice cultivar, the lag phase period may last more than two weeks. During this slow growth period, the number of DD50 units required for a new leaf to emerge increases to about 200 per leaf and continues to increase with each new leaf produced or, under normal growing conditions, 5 to 10 days.

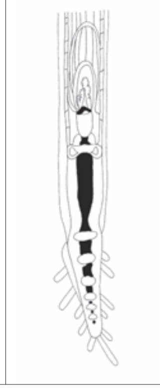
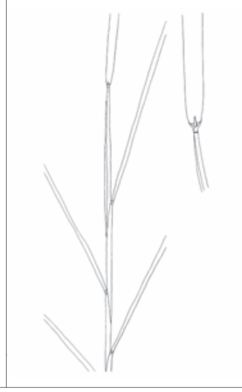
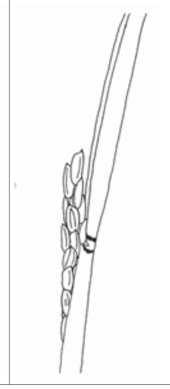
Management Key

The vegetative lag phase in midseason cultivars is characterized by yellowing plants. There is not much activity occurring in the rice; therefore, there is a low nitrogen demand and extra fertilization is not needed. Most of the common cultivars currently grown have a short or unnoticeable vegetative lag period.

Reproductive Phase

The reproductive phase is characterized by culm elongation, a decline in tiller number, booting, emergence of the flag leaf, heading and flowering. The reproductive phase usually lasts approximately 30 days in most cultivars. The beginning of this phase is sometimes referred to as the internode elongation or jointing stage and varies slightly by cultivar and weather conditions. Successive reproductive growth stages provide useful terms so that any two individuals can clearly communicate about the stage of rice (Figure 2-8).

Figure 2-8. Reproductive growth stages with keys for determining growth stage R0 to R9.

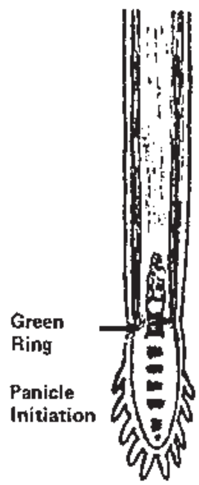
Reproductive growth stages with morphological markers						
Growth Stage	**RO**	**R1**	**R2**	**R3**	**R4**	**R5**
Morphological Marker	**Panicle development has initiated**	**Panicle branches have formed**	**Collar formation on flag leaf**	**Panicle exsertion from boot, tip of panicle is above collar of flag leaf**	**One or more florets on the main stem panicle has reached anthesis**	**At least one caryopsis on the main stem panicle is elongating to the end of the hull**
Illustration						

Reproductive growth stages with morphological markers				
Growth Stage	**R6**	**R7**	**R8**	**R9**
Morphological Marker	**At least one caryopsis on the main stem panicle has elongated to the end of the hull**	**At least one grain on the main stem panicle has a yellow hull**	**At least one grain on the main stem has a brown hull**	**All grains which reached R6 have a brown hull**
Illustration				

The following processes occur during the reproductive phase:

1. **Panicle Initiation** (PI; R0 growth stage, Figure 2-9) is the time when the panicle premordia initiate the production of a panicle in the uppermost node of the culm. At this point, the panicle is not visible to the naked eye. It is sometimes referred to as the green ring stage in rice (Figure 2-9). A thin green band is visible just above the top node and represents the very beginning of internode elongation and is evident for only a couple of days. The duration from R0 to R1 is normally 20 to 30 days and about 200 DD50 units and also the period it takes for growth stage VF-4 to VF-3.

Figure 2-9. Green ring or panicle initiation.



Management Key

Beginning internode elongation (BIE) or panicle initiation (PI) is the time to begin scouting for sheath blight as outlined by the DD50 program.

2. **Internode Elongation** (IE) begins about the time panicle initiation is occurring, continues until full plant height is reached and is followed by heading. The top five internodes are associated with the final five leaves. The first of these elongates before panicle elongation. This stage is also referred to as the "jointing stage" (Figure 2-6). Stem internodes can be distinguished from root internodes by the green color in the stem wall.

3. **Panicle Differentiation** (PD; R1 growth stage, Figure 2-10) is closely associated with "jointing" or the internode elongation stage. PD is roughly equivalent to ½- to ¾-inch internode elongation (Figure 2-10). The duration from the R1 to R2 growth stage is 20 to 30 days and about 600 DD50 units. This means from when the panicle differentiates to when the collar is formed on the flag leaf. It is also the time period required for collar formation on leaves VF-2, VF-1 and VF after the leaf has formed on VF-3. The final five leaves form concurrently with the development of the panicle underneath the sheath.

   At this point, the panicle is 1 to 2 mm in length and the branching of the panicle is visible (Figure 2-11). This is a critical stage during rice plant development.

   At this stage, the environment can have a major effect on rice plant development. The second yield component, number of potential grains per panicle, is set by the time this development stage occurs.

Figure 2-10. **Beginning internode elongation through panicle differentiation.**

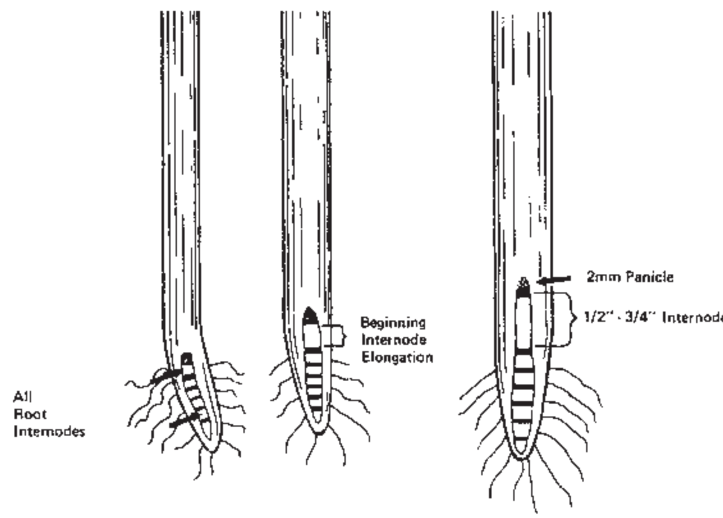
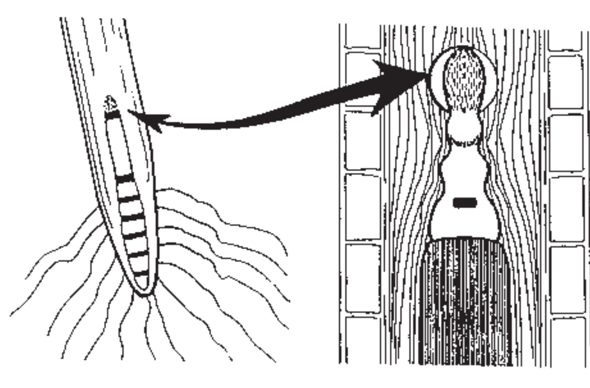


Figure 2-11. **The panicle at the panicle differentiation state of development (2 mm in length). (Left) Panicle exposed by splitting culm lengthwise. (Right) Location within the main culm of the rice plant.**



Management Key

Panicle differentiation is the cut-off time for herbicides such as 2,4-D and propanil. Applications should be made prior to this time to avoid injury to rice.

4. **Booting** (R2 growth stage, Figure 2-12) – This stage is loosely defined as that period characterized by a swelling of the flag leaf sheath which is caused by an increase in the size of the panicle as it grows up the leaf sheath. Full or late boot occurs when the flag leaf has completely extended. Booting is the stage in which meiosis occurs. Environmental stress during this stage may reduce rice grain yield. Late boot occurs about 6 days prior to heading. This date can be predicted by the DD50.

Management Key

Application of propiconizole fungicides should be made to prevent kernel smut during this growth stage.

5. **Heading** (R3 growth stage, Figure 2-8) – The time when the panicle begins to exsert from the boot. (Figure 2-8 shows common types of panicle exsertion.) Heading over an individual field may take over 10 to 14 days due to variations within tillers on the same plant and between plants in the field. Agronomically, ***"heading date"*** or ***"50 percent heading"*** is defined as the time when 50 percent of the panicles have at least partially exserted from the boot. This is in contrast to ***"headed,"*** which refers to the time when 100 percent of the panicles have completely emerged from the boot. Some panicles may never emerge completely from the boot. Across a range of cultivars and conditions, the interval between R3 and R4 is 37 DD50 units and 2.3 days. The duration of this interval depends greatly on sunlight, temperature and humidity conditions. In sunny conditions, the duration of the period from R3 to R4 is shorter and can occur within the same day on some plants. In cloudy, rainy conditions, the period is longer: 5 to 7 days depending on light conditions.

Management Key

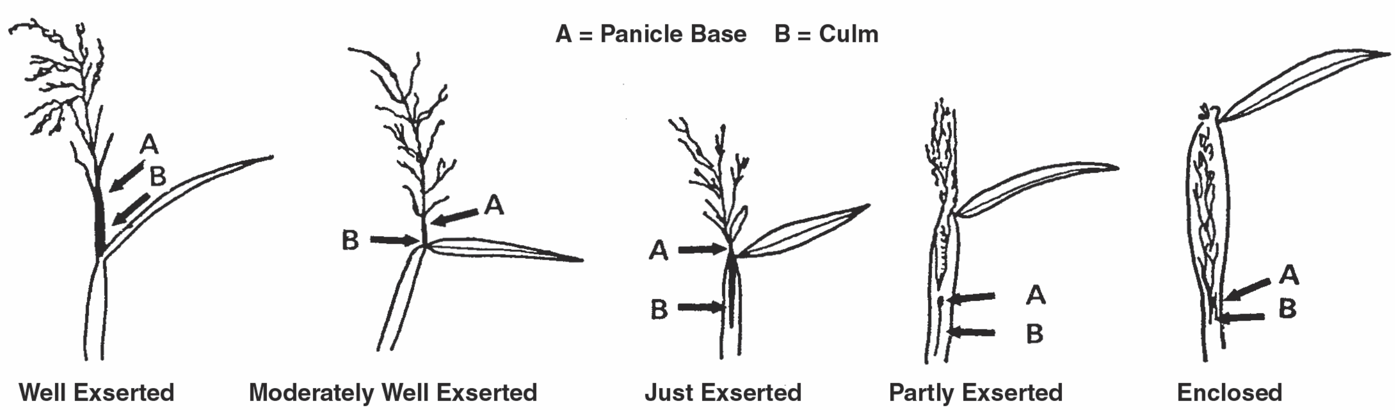
The Arkansas DD50 Management Program uses this same definition of ***"heading date,"*** i.e., when 50 percent of the panicles have at least partially exserted from the boot. Heading date is the last visual check for DD50 accuracy and can be used to predict approximate draining and harvest dates.

The panicle does not fully exsert from the boot at heading. Panicles from some cultivars extend partially out of the boot while others extend 3 to 4 inches beyond the panicle base.

Management Key

Long periods of low sunlight three weeks before and after heading may cause poor exsertion of the panicles and lead to poor grain filling.

Figure 2-12. Common stages of panicle exsertion by rice.



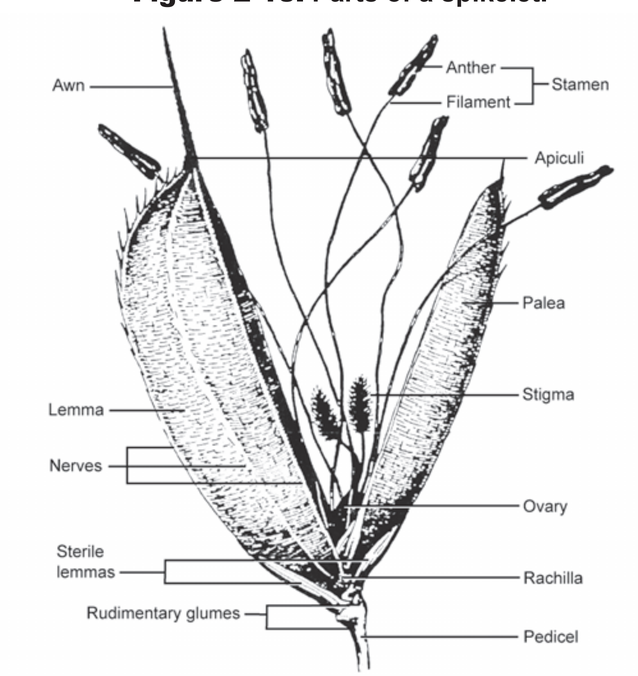
6. **Anthesis** (R4 growth stage, Figure 2-13) or flowering refers to the events between the opening and closing of the spikelet (floret) and lasts for 1 to 2½ hours during which time pollination occurs. Flowering generally begins upon panicle exsertion or on the following day and is consequently considered synonymous with heading.

Anthesis generally occurs between 9 a.m. and 3 p.m. in Arkansas.

The steps involved in anthesis are:

a. The tips of the lemma and palea (hulls) open.
b. The filaments elongate.
c. The anthers exsert from the lemma and palea.
d. As the lemma and palea open further, the tips of the feathery stigma become visible.
e. The filaments elongate past the tips of lemma and palea.
f. The spikelet closes, leaving the anther outside. Anther dehiscence (pollen shed) usually occurs just prior to or at the time the lemma and palea open (step a).

Figure 2-13. Parts of a spikelet.

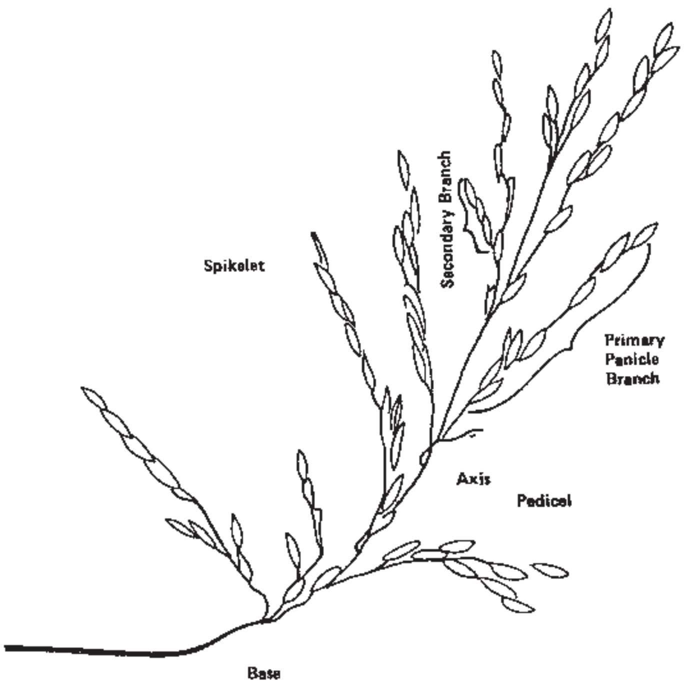


Pollen grains are viable for about 5 minutes after emerging from the anther, whereas the stigma may be fertilized for 3 to 7 days. Rice is primarily a self-pollinating plant. Because it is usually pollinated before the lemma and palea open to release pollen into the air, cross-pollination usually only occurs at a rate of about 1 percent. Fertilization of the ovary by the pollen grain is generally completed within 5 to 6 hours after pollination; at that point, the ovary becomes brown rice. Flowering begins at the tip of the panicle branches and moves down the branch to the panicle base (Figure 2-14). The DD50 interval for R4 to R5 growth stages is about 54, or about three days. Flowering will begin on the upper branches as they emerge from the boot and continue down the panicle to the lower branches. The time interval for flowering of an entire panicle is normally 4 to 7 days. The potential number of filled grains per panicle has been essentially established by the number of fertilized flowers (kernels). Most, but by no means all, grains which are fertilized will eventually fill. The number of filled grains per panicle is primarily determined by conditions and events during this stage since only flowers fertilized can become filled grains.

Management Key

Extremes in temperatures, such as 50°F or less, for two consecutive nights 2 weeks prior to and/or at flowering can cause excessive sterility or blanks. Also, strong winds, rain showers, fertilizer or pesticide applications while blooming is occurring (9 a.m. to 3 p.m.) can increase sterility. During flowering, air temperatures > 95°F may increase blanking.

Figure 2-14.
Parts of a rice panicle.



Ripening Phase

The grain filling and ripening or maturation phase (R6 – R8 growth stages) follows ovary fertilization and is characterized by grain growth. During this period, the grain increases in size and weight as the starch and sugars are translocated from the culms and leaf sheaths where they have accumulated, the grain changes color from green to gold or straw color at maturity and the leaves of the rice plant begin to senesce. Light intensity is very important during this interval since 60 percent or more of the carbohydrates used in grain filling are photosynthesized during this time interval. This period is also affected by temperature. In Arkansas, most long-grains ripen in 35 days, medium-grains in 45 days and short-grains in 50 days. The DD50 program supplies information for approximate maturity dates. The progress of an individual grain from fertilization to completion of grain filling is presented in Figure 2-15.

The final component, individual grain weight, is determined during the ripening stage. Although grain weight is relatively stable for a given cultivar, it can be influenced by the environment. High temperatures tend to reduce the grain-filling period and may reduce grain weight. Low temperatures tend to lengthen the time required for grain fill and ripening. The ripening process may cease after a significant frost occurs and normally slows dramatically when temperatures stay below 50°F for several days.

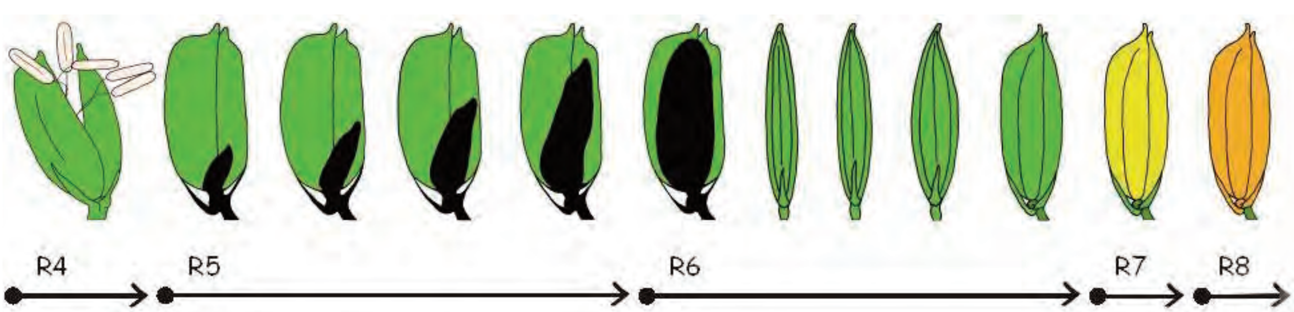
Steps in the ripening process are:

1. **Milk stage** (R6 growth stage) – At this stage, the developing starch grains in the kernel are soft and the interior of the kernel is filled with a white liquid resembling milk. The interval for development from R6 to R7 growth stages is about 90 DD50 units and 3 to 6 days.

2. **Soft dough stage** (R6 growth stage) – The starch in the grain is beginning to become firm but is still soft.

3. **Hard dough stage** (R7 growth stage) – This phase includes the end of grain filling (R7) and the grain-drying stage (R8). The whole grain is firm during this stage and almost ready for harvest. The moisture content for the entire crop is still above 22 percent. The interval for development from R7 to R8 growth stages is about 60 DD50 units or 2 to 5 days.

Figure 2-15. **The development of the individual rice grain from anthesis through grain dry-down.**



4. **Maturity** (R9 growth stage) – The whole grain is hard and ready for harvest. This stage is reached at approximately 20 to 22 percent moisture. The interval for development from R8 to R9 growth stages is about 200 DD50 units and 27 days. For presently used cultivars, temperatures have normally begun to decline from the highs for the growing season although growth stages R6, R7 and R8 are very susceptible to high nighttime air temperatures. Normally rice is harvested prior to R9 for the entire field as the earlier developing grains continue to dry as the later grains are still filling. Consequently, waiting until the last grains fill is impractical and results, normally, in reduced milling quality.

Management Key

Uniform maturity is the key to high milling yields so that harvest can be prompt.

Effect of Temperature on Growth and Development of Rice

Determining optimum temperatures for rice is difficult because the response to temperature varies by biotype (i.e., indica, japonica and javanica), cultivar and plant health before the temperature extreme. Most of the rice grown in the southern USA is a tropical japonica type. Both high and low temperature extremes can influence rice production in Arkansas. However, the overall effects can range from severely reduced yield to merely cosmetic leaf injury.

Japonica types common in the southern USA tend to have reasonably good cold tolerance. The freezing temperatures experienced in 2007 demonstrated this at seedling growth stages. Symptoms of low temperature stress include reduced germination, leaf discoloration, stunting, delayed maturity and increased sterility. The amount of the expression of these symptoms by the rice plant depends on growth stage, duration of the stress and extent of the extreme. Panicle initiation (R0), boot stage (R2) during microsporogenesis and anthesis (flowering – R4) are the stages that are most sensitive to low temperature stress.

High temperature stress causes increased sterility during flowering. High nighttime temperatures during grain filling result in increased respiration which causes the plant to consume more carbohydrates. This reduces the efficiency of photosynthesis during the day, resulting in less filled spikelets. This leads to reduced grain yields. It also results in increased chalky kernels, a thicker bran and aleurone layer, which result in reduced head rice yields.

Chapter 3

Rice Cultivars and Seed Production

Jarrod Hardke, Karen Moldenhauer and Xueyan Sha

Public rice cultivars developed by land-grant institutions such as the University of Arkansas are currently planted on most U.S. rice acreage. This is, in part, due to the relatively small U.S. rice acreage. In contrast, private companies provide the majority of cultivars (varieties) for row crop commodities such as corn, soybeans and wheat. Recent technological advances in production of transgenic crop cultivars, hybrid rice development and specialty markets have stimulated private industry interest in rice breeding and cultivar development (Figure 3-1). Privately-owned cultivars represented approximately 64 percent of the Arkansas rice acreage in 2017, of which 42 percent were hybrids and 45 percent were Clearfield cultivars.Land-grant universities are cooperating with private industry to develop improved cultivars that will assist rice farmers in controlling pests and will add other valuable traits to rice that will help producers and consumers alike. University rice breeding programs remain committed to producing conventional public rice cultivars.

Since 1936, 45 varieties have been developed and released in Arkansas. Between 1936 and 1982, the rice breeding program in Arkansas was carried out by United States Department of Agriculture scientists working at the Rice Research and Extension Center near Stuttgart. The rice check-off program began providing partial financial support for the University of Arkansas rice breeding and development program in 1980, and a rice breeder was hired the same year. Since 1982, 29 varieties have been developed and released by the University of Arkansas rice breeding program. From 1984 to 2009, University of Arkansas-developed varieties were grown on 42 to 86 percent of

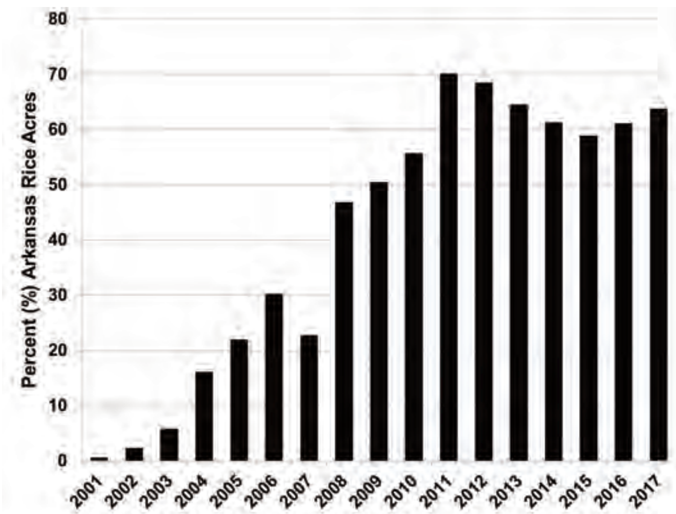


Figure 3-1. Adoption of cultivars marketed by private companies since 2001.

Table 3-1. Description of four seed rice certification classes.

Seed Class	Tag Color	Description
Breeder	White	Breeder seed is not available to the public and is reserved for licensed plant breeders for the production of foundation, registered or certified seed.
Foundation	White	Progeny of breeder seed. Is also reserved for licensed plant breeders. Must be produced under the direct supervision of licensed plant breeder to maintain genetic purity/identity of the variety.
Registered	Purple	Progeny of foundation seed.
Certified	Blue	Progeny of either registered or foundation seed.

the Arkansas rice acreage, depending on the year. Since 2009 the privately owned cultivars have increased dramatically.

Rice Seed Production

Certified rice seed can be divided into four distinct categories (Table 3-1). When a new cultivar is released, the cultivar and its complete description are registered with the National Committee on Registration of Crop Varieties. Foundation seed must be maintained according to these registered standards. The general field inspection and cleaned seed standards for rice seed certification by class are provided in Tables 3-2 and 3-3.

Table 3-2. **Arkansas State Plant Board field inspection standards for seed rice certification†.**

Factor	Seed Class		
	Foundation	Registered	Certified
Other cultivars	None	1 / 5 sq rods	1 sq rod
Noxious weeds	None	None	None
Red rice	None	None	1 plant/acre

†Standards as of 2006. Standards taken from the certified seed directory.

Table 3-3. **Arkansas State Plant Board cleaned seed inspection standards for seed rice certification†.**

Factor	Seed Class		
	Foundation	Registered	Certified
Pure seed (minimum)	98.0%	98.0%	98.0%
Other varieties‡	None	None	2 / lb
GMO varieties††	<0.01%	<0.01%	<0.01%
Other crop seed (maximum)	None	None	2 / lb
All noxious weeds	None	None	None‡‡
Total weed seed (maximum)	0.03%	0.03%	0.08%
Inert (maximum)	2.0%	2.0%	2.0%
Germination (minimum)	80.0%	80.0%	80.0%
Moisture (maximum)	14.0%	14.0%	14.0%

† Standards as of 1999. Standards taken from the certified seed directory.

‡ Other varieties shall not include variations which are characteristics of the varieties.

†† Includes genetically modified varieties, such as Liberty Link rice. Based on regulations passed December 28, 2006.

‡‡ Four pounds of cleaned rice seed is hulled from each lot to determine the noxious weed content, including red rice.

Land where seed rice is grown must not have been planted to a different rice cultivar or uncertified seed of the same cultivar for two previous years. The State Plant Board (#1 Natural Resources Drive, Little Rock, Ark. 72205) is the agency responsible for regulating the seed industry in Arkansas. The State Plant Board sets and enforces seed certification standards and maintains a seed testing laboratory. Descriptions of each cultivar for which certified rice seed is produced in Arkansas are available. Additional information concerning certified seed production standards/regulations and laboratory services can be obtained from the Arkansas State Plant Board in Little Rock, Ark. (501-225-1598). Use of certified seed rice is highly recommended to ensure high quality seed and to aid growers in controlling the spread of noxious weeds.

The certification classes described pertain to "pure-line" varieties. Hybrid rice is developed quite differently. The seed for hybrid rice are the first generation of seed produced after a cross (F1 population). The seed produced from the cross has extremely high vigor, resulting in high yield potential. However, if the second generation of seed is planted, the plants segregate and a wide variety of plant types will result and only a small percentage of those plants will resemble the F1.

Management Key

Plant certified seed to reduce the spread of noxious weeds such as red rice, hemp sesbania, and northern jointvetch. Also, a guaranteed emergence percentage increases the chances of good stand establishment.

Because of the nature of hybrid seed, seed must be obtained by repeating the cross each year. Seed should not be saved from hybrid seed fields. Even in fields where rice follows hybrid rice, volunteer rice from the previous crop will often have a wide range of variability that results from segregation in the F2 generation. Although the production of hybrid seed does not follow the same pattern as conventional varieties (i.e., breeder, foundation, registered, etc.), the seed must conform to standards for germination, noxious weeds, red rice, etc. Hybrid rice must also state the percentage of the seed that is true hybrid (i.e. > 70%), which also reflects the maximum amount of the seed that "self-pollinated." This self-pollinated seed should resemble the female parent. Since only female rows are harvested, these self-pollinated plants will resemble the female parent.

Genetically Modified Rice

Genetically modified rice is rice that has been "engineered" to exhibit a specific trait, such as herbicide resistance, added nutrients, disease resistance or insect resistance, by inserting a gene from another organism that will cause the plant to express that trait. This is the same process that was used to produce glyphosate resistance in soybeans, corn, cotton and other crops. Other transgenic traits include Bt corn and cotton, and numerous other traits in other crops.

While most of the row crops currently produced in Arkansas are genetically modified, rice and wheat are not, due to significant market resistance. These products have been approved by the USFDA and pose no health risks from the consumption of these products. However, consumer resistance in rice and wheat has stifled the adoption of this technology, and to this date no GMO rice is commercially grown in Arkansas.

Clearfield rice represents a successful technological development without utilizing genetic engineering to accomplish herbicide resistance. Clearfield rice does not have genes inserted from other organisms and subsequently is not genetically modified. Clearfield technology has been a successful advancement for rice farmers across the Mid-South and has had rapid adoption by producers.

Rice Cultivar Performance and Agronomic Characteristics

Many agronomic factors must be considered when choosing rice cultivars for production (Table 3-4). The general strengths and weaknesses of available cultivars are summarized in Table 3-5. Environmental factors affect grain and milling yield each year. Because the environment is different each year, several years of testing and observation are needed to make valid comparisons among cultivars. Therefore, data from the 2015-2017 Arkansas Rice Performance Trials have been summarized to better evaluate cultivar performance. Several recently released cultivars have data for only one or two years. For more up-to-date information on cultivar performance and characteristics on different soil textures, consult the most recent edition of the Cooperative Extension Service's publication *Arkansas Rice Performance Trials*, available at your local county Extension office or it may be downloaded at http://arkansas-variety-testing.uark.edu.

Management Key
Select cultivars for specific fields and the conditions and history associated with that field.

Cultivar yield performance data in Table 3-4 should be used with disease ratings included in Chapter 11, Management of Rice Diseases, and nitrogen recommendations in Chapter 9, Soil Fertility, to assist in making cultivar selection. A general description of the major varieties and hybrids is provided in Table 3-5. A brief description of special-purpose varieties is presented in Table 3-6. Cultivars differ in grain and milling yield potential, maturity, straw strength, disease resistance and cooking and processing characteristics. Therefore, consider all of the following factors when selecting a cultivar.

- Field history of disease and cultivar ratings: blast, sheath blight, smuts, stem rot.
- Field history of weed species and herbicide program.
- Soil texture and seedling vigor.
- Seeding method.
- Susceptibility to lodging.
- Maturity group and seeding dates.
- Grain and milling yield performance.
- Irrigation capacity.
- Geographic location.

Additional factors that must be considered before final selection are:

- Market demand for different grain types or cultivars.
- Availability of good quality, red rice-free seed.
- Planting dates and estimated harvest schedules.

Table 3-4. **Results of the Arkansas Rice Performance Trials averaged across the three-year period of 2015-2017.**

Cultivar	Grain Length[1]	Straw Strength[2]	50% Heading[3]	Plant Height	Test Weight	Milled Kernel Weight[4]	Chalky Kernels[4]	Milling Yield				Grain Yield by Year			
								2015	2016	2017	Mean	2015	2016	2017	Mean
		rating	days	inches	lb/bu	mg	%	% Head Rice - % Total Rice				Bushels / Acre			
CL111	L	1.3	81	39	41.9	21.3	2.78	62-70	58-67	58-70	**59-69**	144	149	167	**153**
CL151	L	2.1	81	38	41.3	19.9	3.57	61-70	53-70	58-70	**57-70**	166	164	191	**174**
CL153	L	1.0	84	38	41.7	20.1	1.90	62-69	57-69	61-71	**60-70**	154	169	185	**169**
CL163	L	1.5	86	38	41.3	20.7	2.32	61-70	54-70	60-70	**58-70**	151	150	190	**164**
CL172	L	1.0	84	36	41.1	21.1	1.93	58-69	50-69	60-70	**56-70**	142	161	180	**161**
CL272	M	1.0	84	38	41.7	21.9	2.23	62-70	53-69	52-68	**56-69**	162	176	193	**177**
Diamond	L	1.4	84	40	41.3	21.4	1.61	60-69	55-68	56-69	**57-69**	186	188	206	**194**
Jupiter	M	1.8	85	36	40.3	20.9	2.35	61-68	57-69	59-67	**59-68**	176	167	203	**182**
LaKast	L	1.5	81	41	42.0	21.7	1.53	56-68	55-69	56-70	**56-69**	162	182	188	**177**
MM14	M	1.1	83	33	42.8	21.1	1.46	61-69	--	55-68	**58-68**	155	--	186	**171**
Roy J	L	1.0	88	41	40.8	20.7	1.70	61-70	55-69	60-70	**58-70**	169	167	196	**177**
RT 7311 CL	L	2.0	83	42	38.9	20.5	5.38	--	54-69	50-69	**52-69**	--	208	214	**211**
RT CLXL745	L	2.7	79	43	41.7	22.4	3.27	58-69	46-69	52-70	**52-69**	187	192	202	**194**
RT Gemini 214 CL	L	2.1	88	45	39.1	20.1	4.74	--	53-69	56-69	**54-69**	--	211	215	**213**
RT XP753	L	1.4	80	43	42.2	21.2	3.12	54-69	45-67	49-70	**49-68**	212	231	220	**221**
RT XP760	L	2.5	85	45	41.5	20.8	4.03	59-69	52-68	55-69	**55-69**	207	205	218	**210**
Taggart	L	1.1	87	43	41.2	22.7	1.54	58-70	47-69	59-71	**55-70**	167	179	183	**176**
Thad	L	1.0	87	37	41.5	20.6	1.05	58-69	52-70	57-70	**56-69**	137	147	185	**156**
Titan	M	1.6	80	38	41.3	22.5	1.95	56-68	54-69	51-68	**53-68**	165	192	200	**186**
Wells	L	1.1	85	40	41.4	21.9	1.75	57-70	52-69	55-70	**55-70**	161	171	182	**171**
Mean		**1.5**	**84**	**40**	**41.3**	**21.2**	**2.51**	**59-69**	**53-69**	**56-69**	**56-69**	**167**	**179**	**195**	**182**

[1] Grain Length: L=long grain; M=medium grain.

[2] Relative straw strength based on field tests using the scale: 1=very strong straw, 5=very weak straw; based on percent lodging (2014, 2016 and 2017 data – no lodging in 2015).

[3] Number of days from plant emergence until 50% of the panicles are visibly emerging from the boot.

[4] Data from Riceland Grain Quality Lab, 2014-2016.

Table 3-5. **Brief description of general rice cultivar characteristics.**

Cultivar	Grain Type	Year Released and Source	Highlights
Antonio	L	2012 – Texas	A short season, semi-dwarf long-grain variety with very good yield potential and milling quality. Similar to Cocodrie for agronomic characteristics.
Bengal	M	1992 – Louisiana	A short season, semi-dwarf medium-grain variety with good yield potential and milling quality. It has a preferred large grain size.
Caffey	M	2011 – Louisiana	A short season, semi-dwarf medium-grain variety with excellent yield potential and milling quality. Susceptible to blast, sheath blight and panicle blight.
Cheniere	L	2003 – Louisiana	A short season, semi-dwarf long-grain variety with good yield potential and milling quality comparable to Cypress. Susceptible to sheath blight and blast.
CL111	L	2008 – BASF, Horizon Ag	An early season, semi-dwarf long-grain Clearfield variety similar to CL 131. Susceptible to blast, straighthead, and bacterial panicle blight.
CL151	L	2007 – BASF, Horizon Ag	A mid-season, semi-dwarf long-grain Clearfield variety similar to Cocodrie with good yield potential and high tolerance to Newpath herbicide. It is very susceptible to blast and straighthead, and susceptible to lodging and sheath blight.
CL153	L	2016 – BASF, Horizon Ag	A mid-season, semi-dwarf long-grain Clearfield variety similar to CL151 with good yield potential and high tolerance to Newpath herbicide. Susceptible to sheath blight, kernel smut, and false smut. Moderately susceptible to blast.
CL163	L	2015 – BASF, Horizon Ag	A mid-season, semi-dwarf long-grain Clearfield variety with good yield potential and milling quality and high tolerance to Newpath herbicide. Susceptible to sheath blight and blast. Moderately susceptible to bacterial panicle blight. High amylose content.
CL172	L	2016 – BASF, Horizon Ag	A mid-season, semi-dwarf long-grain Clearfield variety with good yield potential and milling quality. High tolerance to Newpath herbicide. Moderately susceptible to sheath blight, blast, bacterial panicle blight, and kernel smut. Susceptible to false smut.
CL272	M	2016 – BASF, Horizon Ag	A mid-season, medium-grain Clearfield variety. High tolerance to Newpath herbicide. Very susceptible to bacterial panicle blight. Susceptible to sheath blight and blast.
Della-2	L-A	2012 – Louisiana	A short season, semi-dwarf long-grain aromatic variety with good yield and very good grain quality. Improved lodging compared to Della.
Diamond	L	2016 – Arkansas	A mid-season, long-grain variety with excellent yield potential and good milling quality. Very good straw strength. Susceptible to blast and sheath blight, moderately susceptible to bacterial panicle blight. Very susceptible to false smut.
Francis	L	2002 – Arkansas	A short season, long-grain variety with excellent yield potential, susceptible to rice blast and very susceptible to kernel smut. It is the best long grain for high pH and salt soils of NE Arkansas west of Crowley's ridge but should not be stressed for water due to blast concerns.
Jazzman-2	L-A	2011 – Louisiana	A mid-season, Jasmine-type aromatic variety with fair yield and good milling compared to Jazzman. Susceptible to sheath blight, bacterial panicle blight, and straighthead.
Jupiter	M	2006 – Louisiana	A mid-season, semi-dwarf, medium-grain variety with excellent yield potential and milling quality. It has a small grain size but has moderate resistance to bacterial panicle blight.

(Continued on page 26)

Table 3-5. **Brief description of general rice cultivar characteristics. (cont.)**

Cultivar	Grain Type	Year Released and Source	Highlights
LaKast	L	2014 – Arkansas	A mid-season, long-grain variety with excellent yield potential and good milling quality. Susceptible to blast and sheath blight.
Mermentau	L	2012 – Louisiana	A mid-season, semi-dwarf, long-grain variety with good yield potential and physical characteristics similar to Cocodrie, Cheniere, and Catahoula.
MM14	M	2014 – Missouri	A mid-season, medium-grain variety with good yield potential. Susceptible to bacterial panicle blight.
Rex	L	2010 – Mississippi	A short season, semi-dwarf long-grain variety with excellent yield potential and good milling quality. Very good straw strength, but is susceptible to most diseases.
Roy J	L	2010 – Arkansas	A mid-season, long-grain variety with excellent yield potential and good milling quality. Excellent straw strength. Susceptible to blast and moderately susceptible to sheath blight.
RT 7311 CL	L	2016 – RiceTec, Inc.	A short season, long-grain hybrid with excellent yield potential. Moderately susceptible to sheath blight.
RT CLXL729	L	2007 – RiceTec, Inc.	A short season, long-grain Clearfield hybrid with excellent yield potential and moderately susceptible to sheath blight and moderately resistant to blast.
RT CLXL745	L	2008 – RiceTec, Inc.	A short season, long-grain Clearfield hybrid with excellent yield potential, moderately susceptible to sheath blight, and moderately resistant to blast, and susceptible to lodging. Reported to have improved tolerance to shattering.
RT CLXP756	L	2011 – RiceTec, Inc.	A mid-season, long-grain Clearfield hybrid with good yield potential and average milling quality. Similar to CL XL729.
RT CLXL4534	L	2013 – RiceTec, Inc.	A short season, long-grain Clearfield hybrid with good yield potential.
RT Gemini 214 CL	L	2016 – RiceTec, Inc.	A mid-season, long-grain Clearfield hybrid with excellent yield potential. Susceptible to sheath blight.
RT XL723	L	2005 – RiceTec, Inc.	A short season, long-grain hybrid with excellent yield potential, average milling quality; resistant to blast and moderately susceptible to sheath blight.
RT XL753	L	2011 – RiceTec, Inc.	A short season, long-grain hybrid with excellent yield potential. Resistant to blast, moderately susceptible to sheath blight and straighthead.
RT XL760	L	2014 – RiceTec, Inc.	A short season, long-grain hybrid with good yield potential.
Taggart	L	2009 – Arkansas	A mid-season, long-grain variety with very good yield potential and average milling quality. Resistant to straighthead. Moderately susceptible to sheath blight and rice blast.
Thad	L	2016 – Mississippi	A mid-season, long-grain variety with good yield potential and milling quality. Susceptible to blast, sheath blight, and straighthead, very susceptible to false smut. High amylose content.
Titan	M	2016 – Arkansas	A short season, medium-grain variety with excellent yield potential. Moderately susceptible to blast and bacterial panicle blight. It has a preferred large grain size.
Wells	L	1999 – Arkansas	A short season, long-grain variety with excellent yield potential, average to good milling quality, large kernel size similar to Lemont, but is susceptible to rice blast. Only moderately susceptible to kernel smut and most other diseases.

Table 3-6. Brief description of specialty cultivars.

Variety/Hybrid	Year Released and State	Highlights
AB647	1996 – Anheuser Busch	Selection from Congui, a Chinese indica rice, that is a long-season medium-grain with high yield potential and atypical cooking qualities. Used for brewing.
Baldo	Italy	A very short-season, large-kerneled medium-grain used for risotto.
Bolivar	2001 – Texas	A very short-season long-grain with the same parboiling and canning properties as Dixiebelle.
Della	1971 – Louisiana	Aromatic, mid-season long-grain with low yield potential and average milling quality that is susceptible to lodging.
Dellmati	1999 – Louisiana	A semi-dwarf, aromatic long-grain which elongates when cooked.
Dellmont	1992 – Texas	Semi-dwarf, aromatic long-grain with good yield potential and milling quality.
Dellrose	1995 – Louisiana	A semi-dwarf, aromatic long-grain with high yield potential and good milling quality. It has grain size similar to Della.
Dixiebelle	1996 – Texas	Short-season long-grain with 'Newrex' quality; specialty rice used for canning and steam tables.
Hidalgo	2005 – Texas	A semi-dwarf long-grain with good yield potential and milling quality. Cooking type similar to Toro. It is susceptible to blast and moderately susceptible to sheath blight.
Jasmine-85	1990 – Texas	Aromatic long-grain with good yield potential and poor milling quality.
Jazzman	2008 – Louisiana	Aromatic long-grain with good yield potential and milling quality.
Jazzman-2	2010 – Louisiana	A semi-dwarf, fragrant long-grain with good yield potential, good milling quality and very strong aroma. Jazzman-2 is susceptible to rice sheath blight, bacterial panicle blight and straighthead but moderately resistant to blast.
JES	2009 – Arkansas/Florida	Aromatic long-grain with good yield potential and milling quality.
Koshihikari	Japan	A premium-quality short-grain with low yield potential and good milling quality. It is the standard for Japanese quality.
Neches	2005 – Texas	A long-grain waxy rice with good yield potential (similar to Lemont) used for flour and starch in processing industry. Moderately resistant to blast and very susceptible to sheath blight.
Pirogue	2002 – Louisiana	A short-season short-grain with good yield potential and good milling quality.
Sabine	2006 – Texas	Short-season long-grain with 'Dixiebelle' quality. Similar agronomic traits as Dixiebelle, with higher yield potential. Specialty rice used for canning and steam tables.
Sierra	2005 – Texas	An aromatic long-grain with the fragrance and cooking qualities of a basmati-style rice.
Toro 2	1984 – Louisiana	Special-purpose, low amylase and low gelatinization temperature, long-grain rice. Toro 2 cooks moist and sticky like a medium-grain rice.

Seeding a large percentage of acreage in a single cultivar is not recommended. Planting several cultivars minimizes the risk of damage from adverse weather and disease epidemics and allows for a timely harvest which increases the chances of obtaining good quality seed with maximum milling yields. Since environmental conditions can greatly affect yield, it is also recommended to spread seeding dates so that cultivars do not reach critical growth stages at the same time. Consult the DD50 computer program to plan harvest schedules based on emergence dates of cultivars.

Management Key

Plant multiple cultivars across the farm acreage to reduce risk from diseases and adverse weather.

Other Cultivars

Cultivar characteristics and yield performance data presented in this section are for the rice cultivars grown on the majority of rice acreage in Arkansas. Information on other "specialty cultivars" or "older cultivars not commonly produced" may be available from the University of Arkansas Cooperative Extension Service and Agricultural Experiment Station upon request.

Kernel Classification and Cooking Qualities

Rice cultivars are classified as either long-, medium-, or short-grain by their rough, brown and milled kernel dimension ratios (Table 3-7). Since kernel type, dimension and cooking quality are of primary importance to millers and processors, these characteristics are considered in cultivar development.

Table 3-7. Grain type classification based on kernel dimensions.

Grain Type	Grain Form	Kernel Length/Width Ratio
Long	Rough	≥ 3.4 to 1
Long	Brown	≥ 3.1 to 1
Long	Milled	≥ 3.0 to 1
Medium	Rough	≥ 2.3 to 1
Medium	Brown	≥ 2.1 to 1
Medium	Milled	≥ 2.0 to 1
Short	Rough	≥ 2.2 to 1
Short	Brown	≥ 2.0 to 1
Short	Milled	≥ 1.9 to 1

The cooking qualities of rice depend on the chemical composition of the rice grain. The rice kernel is made of starch. Starch consists mainly of highly branched chains called amylopectin and some linear chains with fewer branches called amylose. The temperature at which the rice starch forms a gel when cooking is the gelatinization temperature. The amylose content and gelatinization temperature influence the cooking quality of the rice grain.

Most long-grain cultivars grown in the southern U.S. have cooking qualities described as typical. Cultivars with "typical southern U.S. cooking quality" produce rice that is dry and fluffy (nonsticky) when cooked. These cultivars are parboiled, quick-cooked or used in processed rice products. Aromatic long-grain cultivars, such as Della, Dellmont and Jasmine 85, tend to have similar textures when cooked but also have a distinct taste and aroma when cooking. Cultivars such as Toro-2 are sticky rices due to low amylose contents and should not be commingled with other long-grain cultivars because of their nontypical physiochemical characteristics.

Medium-grain cultivars produced in the southern U.S. produce moist, sticky rice when cooked, in contrast to the dry, fluffy, long-grain types and are preferred for dry breakfast cereals, soups, baby foods and brewing purposes. Toro-2 is a low amylose long-grain variety that cooks sticky like medium-grain cultivars.

Traditional southern U.S. long-grain rices, such as Cypress, Wells, Roy J and Diamond, have intermediate amylose contents of 20 to 24 percent and intermediate gelatinization temperatures of 70° to 75°C (158 to 167 °F). In comparison, extra high amylose rices, such as Rexmont and Dixiebelle, have an amylose content greater than 24 percent and intermediate gelatinization temperatures. The medium- and short-grain rices, such as Bengal, Nortai, Pirogue and Koshihikari, have low amylose content (10 to 20 percent) and gelatinization temperatures less than 70°C (158°F).

Traditional southern U.S. long-, medium- and short-grain cultivars are translucent or clear in appearance. Waxy or glutinous rices have an amylose content of only 1 to 2 percent, a low gelatinization temperature (< 70°C; <158°F) and an opaque appearance. They are often used in sweets, frozen products and as thickening agents. In general, if the amylose content is intermediate to high, the rice cooks drier and less sticky. Low amylose rice tends to cook stickier, and waxy rices are very sticky. The starch-iodine-blue test is used to estimate amylose content during early stages of cultivar development.

Chapter

4

Rice Stand Establishment

Jarrod Hardke, Yeshi Wamishe, Gus Lorenz and Nick Bateman

Stand establishment is the first step to a successful rice crop. Factors that influence stand establishment include cultivar, seedling vigor, seeding method, seeding date, soil properties, seeding rate, seed treatments, environment and geographic location. Later management decisions are affected by stand density and uniformity. The goal of stand establishment is to obtain a uniform stand of healthy rice seedlings. Uniformity of emergence is important for accuracy of the DD50 program, pesticide application timing, drain timing for straighthead prevention, milling yield, irrigation termination, yield and harvest.

Seeding Rate

Seeding rates vary depending on cultivar, due to differences in seed size and/or weight. The RICESEED program is available to assist growers in determining the correct seeding rate for different seeding dates and methods, soils, seedbed conditions and cultivars. This program is available at local county Extension offices or may be accessed online from the Cooperative Extension Service web site at http://riceseed.uaex.edu/.

Table 4-1 provides a list of seed weights and seeding rates needed to obtain the different number of seeds per square foot for commonly grown cultivars. Under most conditions where rice is drill-seeded, 30 seeds per square foot are adequate to obtain the optimum stand density of 10 to 20 plants per square foot for conventional varieties (or 6 to 13 seedlings per 7.5-inch drill row foot). For hybrids, 10 to 15 seeds per square foot is needed to obtain optimum stand density of 6 to 10 plants per square foot (or 4 to 6 seedlings per 7.5-inch drill row foot). Stand densities above the optimum density increase disease, plant height and lodging.

Table 4-1. Seeding rates for different seeds per square foot based on seed weight.

Cultivar	Seed Weight†	Seeds/lb	Number of Seed/Sq. Ft.							
			10	12	14	25	30	35	40	45
			Seeding Rate, lbs/A							
CL111	23.09	19,662	--	--	--	55	66	78	89	100
CL151	24.13	18,813	--	--	--	58	69	81	93	104
CL153	24.01	18,909	--	--	--	58	69	81	92	104
CL163	25.11	18,079	--	--	--	60	72	84	96	108
CL172	23.31	19,481	--	--	--	56	67	78	89	101
CL272	25.32	17,932	--	--	--	61	73	85	97	109
Diamond	24.58	18,470	--	--	--	59	71	83	94	106
Jazzman-2	22.37	20,295	--	--	--	54	64	75	86	97
Jupiter	26.52	17,119	--	--	--	64	76	89	102	115
LaKast	25.46	17,832	--	--	--	61	73	85	98	110
Mermentau	21.58	21,038	--	--	--	--	--	--	--	--

† Grams per 1,000 grains or milligrams per seed.

(Continued)

Table 4-1. **Seeding rates for different seeds per square foot based on seed weight. (cont.)**

Cultivar	Seed Weight†	Seeds/lb	Number of Seed/Sq. Ft. 10	12	14	25	30	35	40	45
			Seeding Rate, lbs/A							
RT 7311 CL	23.54	19,286	23	27	32	--	--	--	--	--
RT CL XL729	22.82	19,895	22	26	31	--	--	--	--	--
RT CL XL745	23.46	19,352	23	27	32	--	--	--	--	--
RT XL XP756	23.49	19,327	23	27	32	--	--	--	--	--
RT Gemini 214 CL	21.89	20,740	21	25	29	--	--	--	--	--
RT XL723	22.84	19,877	22	26	31	--	--	--	--	--
RT XL753	23.89	19,004	23	28	32	--	--	--	--	--
RT XP754	23.49	19,327	23	27	32	--	--	--	--	--
RT XL760	22.88	19,843	22	26	31	--	--	--	--	--
Roy J	22.74	19,965	--	--	--	55	65	76	87	98
Taggart	25.90	17,529	--	--	--	62	75	87	99	112
Thad	25.29	17,952	--	--	--	61	73	85	97	109
Titan	27.24	16,667	--	--	--	65	78	91	105	118
Wells	25.98	17,475	--	--	--	62	75	87	100	112

† Grams per 1,000 grains or milligrams per seed.

Below optimum stand densities are capable of producing high yields provided that plant distribution is uniform, weeds are controlled and additional nitrogen is applied to increase tillering. Most cultivars compensate for low seedling population by increasing tillering and the number of grains per panicle. Seeding rates should be increased by 10 percent for no-till seedbeds and early seeding; 20 percent for broadcast seeding, poor seedbed condition or clay soils; and 30 percent for water-seeding. In fields with a history of severe infestations of grape colaspis larvae (lespedeza worm) or fields with chronic infestations, seeding rates should be increased to help compensate or use a recommended seed treatment insecticide.

The recommended seeding rate of 30 seeds per square foot for conventional varieties is a reduction from previous recommendations. Recent studies suggest that seeding rates may be reduced by 25 percent from older recommendations and still obtain optimum yields (Table 4-2). Seeding rates as low as 67.5 pounds per acre (1.5 bushels/acre) result in grain yields and milling yields similar to those obtained with higher seeding rates. Reduced seeding rates lower the potential for sheath blight and the amount of fungicide needed on varieties such as CL151 and CL161 by reducing the risk of excessive plant populations.

Table 4-2. **Influence of seeding rate on grain yields of four rice varieties averaged across five locations in 2015 and 2016.**

Seed Rate	Grain Yield CL172	Diamond	LaKast	Roy J
lbs/acre	bu/A			
20	142	165	159	153
40	154	175	173	164
60	162	177	175	167
80	160	183	175	169
100	162	183	181	170

Source: Hardke unpublished data.

Management Key

Use the RICESEED program to calculate optimum seeding rates for specific fields to avoid excessive plant populations. Proper calibration of drills is an important step in obtaining optimum seeding rates.

Recommended drill row widths for rice are between 4 and 10 inches. Limited research data suggests that under most conditions row widths between 4 and 10 inches can produce similar yields. However, as row width increases, the importance of uniform stand density also increases. Several studies show a trend for higher grain yields with narrower drill row spacing, thus a drill row spacing of 6 to 8 inches is ideal (Table 4-3). However, other practical considerations should be made regarding row spacing. For example, wider row spacing is desirable on clay soils where clods may become lodged between the coulters on narrow row drills. Seeding rates do not need to be adjusted for differences in drill row widths in the 4- to 10-inch range. Table 4-4 provides the number of seed per row foot for 6- to 10-inch drill row spacing and seeding rates for drill calibration.

Table 4-3. **Influence of row spacing on grain yields of three rice varieties at three locations during 2004.**

Cultivar	Grain Yield					
	RREC†		SEREC		Lake Hogue	
	7"	10"	7"	10"	7"	10"
	bu/A					
Banks	190	170	173	162	169	160
Cybonnet	169	150	128	125	175	166
Francis	206	180	160	154	213	193

† RREC = Rice Research and Extension Center, Stuttgart; SEREC = Southeast Research and Extension Center, Rohwer; and Lake Hogue = Poinsett County.

Source: Frizzell et al., 2006. p. 270-275. *B.R. Wells Rice Res. Studies 2005.* Ark. Agr. Exp. Sta. Res. Ser. 540.

Table 4-4. **Seed spacing for calibration drills.**

Seeds/ Sq. Ft.	Seed Per Row Foot for Different Row Spacings				
	6"	7"	8"	9"	10"
20	10	12	13	15	17
30	15	17	20	23	25
40	20	23	27	30	33
50	25	29	33	38	42
60	30	35	40	45	50
70	35	41	47	53	58
80	40	45	54	60	68

Seed Treatments

Seed treatments are often considered "insurance" and include fungicides, fertilizers, growth regulators and insecticides (when available). Although most seed treatments are generally inexpensive, they are not always recommended. The decision to use seed treatments should be based on planting date, tillage/planting method, cultivar, soil texture, disease problems and field history. Most seed treatments are for use only by commercial seed treaters, although a few are available as planter box treatments.

Fungicide seed treatments (Table 4-5) are generally recommended for early planting, clay soils, reduced tillage (especially no-till) or on fields that have a

Table 4-5. **Fungicide seed treatment products and disease control spectrum for rice†.**

Disease	Fungicide	Active Ingredient	FRAC Code	Rate/cwt Seed	Comments
Pythium diseases	Allegiance FL	metalaxyl	4	0.75 - 1.5 fl oz	Apply with commercial seed-treating equipment.
	Apron XL	mefenoxam	4	0.32 - 0.64 fl oz	Apply with commercial seed-treating equipment. Use higher rates for early planting or other severe disease situations.
Rhizoctonia seedling diseases, general seed rots	RTU-Vitavax-Thiram	carboxin + thiram	7 + M3	6.8 fl oz	Apply with commercial seed-treating equipment or use as a pour-on hopper-box treatment.
	Vitavax 200	carboxin + thiram	7 + M3	4 fl oz	Apply with commercial seed-treating equipment.
	Maxim 4 FS	fludioxonil	12	0.08 - 0.16 fl oz	Apply with commercial seed-treating equipment. Use higher rates for severe disease situations.

† Specific product labels should be consulted for use rates and precautions. Some products may be mixed to broaden the spectrum of seed protection. The highest labeled rates should be used for very early planting or other situations where seed germination and emergence may be delayed by environmental conditions. The effectiveness of most products is relatively short-lived under field conditions, providing about 2 to 3 weeks of seed protection at most.

(Table continued)

Table 4-5. **Fungicide seed treatment products and disease control spectrum for rice†. (cont.)**

Disease	Fungicide	Active Ingredient	FRAC Code	Rate/cwt Seed	Comments
Pythium, Rhizoctonia, general seed rots	Vitavax 200 + Allegiance FL	carboxin + thiram + metalaxyl	7 + M3 + 4	4 fl oz + 0.375 fl oz	Apply with commercial seed-treating equipment.
	Apron XL LS + Maxim 4 FS	mefenoxam + fludioxonil	4 + 12	0.32 - 0.64 fl oz + 0.08 - 0.16 fl oz	Apply with commercial seed-treating equipment. Use higher rates for early planting or severe disease situations.
	Dynasty	azoxystrobin	11	0.153 - 1.53 fl oz	Commercial seed treaters only. Usually sold with Apron XL and Maxim on rice to improve seedling disease control. To reduce seedborne blast, data suggests rates of Dynasty above 0.75 fl oz per cwt. The use of a seed treatment fungicide to minimize seedborne blast does not mean complete control of the disease later in the season and the field should still be scouted for blast disease and managed with deeper flood and foliar fungicides. CruiserMaxx Rice may be used for a wider range of ai's.
	Trilex 2000	trifloxystrobin + metalaxyl	11 + 4	1 - 2 oz	See label.
	EverGol Energy	prothioconazole + penflufen + metalaxyl	3 + 7 + 4	1 oz	Commercial seed treatment only.
	CruiserMaxx Rice	thiamethoxam + azoxystrobin + fludioxonil + mefenoxam	--- + 11 + 12 + 4	7 fl oz	

† Specific product labels should be consulted for use rates and precautions. Some products may be mixed to broaden the spectrum of seed protection. The highest labeled rates should be used for very early planting or other situations where seed germination and emergence may be delayed by environmental conditions. The effectiveness of most products is relatively short-lived under field conditions, providing about 2 to 3 weeks of seed protection at most.

history of poor seedling emergence and seedling disease. Under the right conditions, fungicide seed treatments can result in a 10 to 20 percent stand increase over untreated seed. However, there may not be a yield increase since rice can compensate for thin, uniform stands by increased tillering. Fungicide seed treatments do not speed the rate of emergence like growth regulator treatments, nor do they control kernel or false smut. The use of fungicide-treated seed also does not guarantee that seedling disease will not impact stand density, especially three to four weeks after planting. Most fungicide seed treatments are specific for certain groups of fungi that may cause stand loss. Refer to MP154, *Plant Disease Control Products Handbook* (www.uaex.edu/publications/mp-154.aspx), for the latest information on fungicide seed treatments.

Recommended growth regulator seed treatments are currently limited to gibberellic acid (or GA3) products which include Release® and GibGro®. Seed treatments containing GA3 do not prevent seedling disease and are not recommended for water-seeded rice. The use of GA3 is highly recommended for semi-dwarf rice cultivars, cultivars having poor seedling vigor, on clay soils, reduced tillage situations and early seeding dates. Use of GA3 treated seed may increase uniformity of emergence, minimize the effects of deep seed placement and speed up germination and emergence and has been well researched since 1988. Growth regulator seed treatments may be used in combination with other types of seed treatments, but always check the product labels for mixing instructions and precautions prior to use. When treated with GA3, rice seedlings may appear tall and yellow shortly after emergence. Seedlings normally outgrow these symptoms within one or two weeks after emergence. If a stand failure occurs and a residual herbicide has been used, check the herbicide and GA3 product labels for replanting restrictions/recommendations with GA3-treated seed. For example, the Prowl herbicide label recommends that GA3-treated seed not be used to replant fields that have been treated with Prowl.

Management Key

Use gibberellic acid (GA3) seed treatments when the following conditions exist:

- Semi-dwarf rice cultivars
- Cultivars with poor seedling vigor
- Rice planted on clay soils
- Reduced tillage rice production
- Early-planted rice

The use of fertilizer (i.e., Zn) seed treatments is addressed in later chapters that concern fertilization practices. Check with your local county Extension office for the most recent recommendations for use of new seed treatment products.

Insecticide seed treatments (Table 4-6) are recommended for fields with a history of grape colaspis or rice water weevil or soil types most commonly associated with these insects (silt loam for grape colaspis). Even in the absence of insect pressure, insecticide seed treatments have generally been observed to increase seedling emergence and early season vigor and can sometimes increase yield. Refer to MP144, *Insecticide Recommendations for Arkansas* (www.uaex.edu/publications/pdf/mp144/mp144.pdf) for the latest information on insecticide seed treatments.

Seeding Date and Soil Temperatures

The daily maximum, mean and minimum soil temperatures measured at a 4-inch depth at three University of Arkansas Division of Agriculture Experiment Stations are provided in Table 4-7. Rice should be seeded in a seedbed that is conducive to good seed-to-soil contact when the daily average soil

Table 4-6. Insecticide seed treatment products and insect control spectrum for rice†.

Insecticide	Active Ingredient	Rate/cwt seed	Comments
Dermacor X-100	chlorantraniliprole	1.5 - 6.0 fl oz (see label)	Control of rice water weevil larvae. Suppression only of grape colaspis larvae. See label.
NipsIt INSIDE 5 FS	clothianidin	1.92 fl oz	Control of rice water weevil and grape colaspis larvae. Use only on dry-seeded rice. DO NOT spray crop with another neonicotinoids insecticide after using NipsIt INSIDE. DO NOT use near fish or crawfish farms.
CruiserMaxx Rice	thiamethoxam	7.0 fl oz	Control of rice water weevil and grape colaspis larvae. DO NOT plant or sow Cruiser-treated seed by aerial application. Cruiser is NOT labeled for use in water-seeded rice. DO NOT use treated fields for aquaculture of edible fish or crustaceans. DO NOT exceed 120 lbs seed per acre.
This information was current as of August 1, 2018, and applies only to Arkansas and may not be appropriate for other states or locations. The listing of any product in this publication does not imply endorsement of that product or discrimination against any other product by the University of Arkansas Division of Agriculture. *Every effort was made to ensure accuracy, but the user of any crop protection product must read and follow the most current label on the product - **The Label is the Law.*** For further assistance, contact the local Cooperative Extension Service office.			

† Specific product labels should be consulted for use rates and precautions. Some products may be mixed to broaden the spectrum of seed protection. The highest labeled rates should be used for very early planting or other situations where seed germination and emergence may be delayed by environmental conditions. The effectiveness of most products is relatively short-lived under field conditions, providing about 2 to 3 weeks of seed protection at most.

temperature at the 4-inch depth is above 60°F. Soil temperature measurements taken from Rohwer, Stuttgart and Keiser indicate that the average soil temperature at a 4-inch depth reaches 60°F about April 8, 11 and 16, respectively. Assuming adequate moisture for germination, rice emergence should occur within approximately 8, 14 and 20 days after seeding when 4-inch soil temperatures average 70°, 65° and 60°F, respectively (based on data from seeding date studies).

Management Key

Seeding when the average soil temperature at the 4-inch depth is above 60°F enhances uniform emergence and reduction in potential for seedling diseases.

When rice is planted early, more time is required for germination, emergence and development to the 5-leaf stage. For example, in the 2015 Rice DD50 Research and Development Studies, 20 rice cultivars seeded on April 3 required an average of 11 days from seeding to emergence and an additional 36 days to reach the 5-leaf stage for flooding (Table 4-8). In comparison, rice planted June 3 only required 7 days for emergence and an additional 16 days to reach the 5-leaf growth stage. The extended time between planting and flooding at the 5-leaf growth stage may increase production costs associated with flushing and weed control.

Specific beginning and ending seeding dates were once suggested, by cultivar, for the geographic regions of south, central and north Arkansas. However, seeding date studies conducted during the past 10 years suggest these cultivar selection guidelines were not appropriate for late seeding. Depending on environmental conditions, cultivars with longer growing seasons may produce higher yields than very short-season cultivars when seeded late. Cultivar selection decisions for late-planted rice should be made based on cultivar performance in

Table 4-7. Minimum, maximum and mean undisturbed soil temperatures at a 4-inch depth for selected dates at three locations in Arkansas.

Location	Rohwer, SEREC†			Stuttgart, RREC‡			Keiser, NEREC†		
Latitude	33.45 N			34.49 N			35.68 N		
Soil Texture	Perry Clay			DeWitt Silt Loam			Sharkey Clay		
Daily Temp.	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Date	4 inch undisturbed soil temperature, °F								
March 15	50	57	54	46	56	51	44	54	49
April 1	53	52	57	49	62	55	46	55	51
April 15	60	69	64	56	69	63	55	64	59
May 1	63	74	69	59	71	65	58	69	64
May 15	69	75	72	66	79	72	64	81	73
May 31	69	78	74	69	78	73	70	74	72

†Temperatures are the six-year average from 1990 to 1995.
‡Temperatures are the nine-year average from 1990 to 1998.

Table 4-8. General seeding, seedling emergence, and flooding date information for the DD50 seeding date study in 2015 at the Rice Research and Extension Center near Stuttgart, AR.

Parameter	Planting Date					
	March 21	April 5	April 18	May 2	May 19	June 15
Emergence date	April 2	April 16	May 3	May 15	May 31	June 27
Flood date	May 11	May 16	June 2	June 13	June 29	July 19
Days from seeding to emergence	12	11	15	13	12	12
Days from seeding to flooding	51	41	45	42	41	34
Days from emergence to flooding	39	30	30	29	29	22

Source: Castaneda et al., 2017. *B.R. Wells Rice Res. Studies 2018.* Ark. Agr. Exp. Sta. Res. Ser.

seeding date studies. Results from annual seeding date studies are published each year in *Rice Information Sheets* that summarize cultivar yield performance among different locations and seeding dates.

Management Key

Rice planted within the early window (Table 4-10, Table 4-10) performs better than rice planted in later windows; however, there may be increased stand establishment risks in some fields planted at the earliest dates due to cool, wet soil conditions.

Table 4-9. Yields for studies conducted in Stuttgart comparing seed treatments across multiple planting dates.

Planting Date	Seed Treatment			
	Fungicide Only	Cruiser-Maxx	NipsIt INSIDE	Dermacor X-100
	Bu/A			
Early April	170	190	189	185
Mid-April	155	162	159	163
Early May	172	175	171	172
Mid-May	161	172	163	164
Early June	156	165	163	163
Mid-June	167	168	172	173

† CruiserMaxx, NipsIt INSIDE and Dermacor X-100 all received the same fungicides as the fungicide-only treatment.

Source: Lorenz and Hardke, unpublished data.

Insecticide seed treatment studies were conducted at the Rice Research and Extension Center (RREC) to evaluate the benefits of insecticide seed treatments across a range of planting dates (Table 4-9). Results suggest that insecticide seed treatments provide a yield benefit to growers across the range of planting dates common in Arkansas. Specific growing season conditions and insect pressure will influence results in a given season.

Seeding date studies conducted at the Rice Research and Extension Center (RREC), located near Stuttgart, Arkansas, were analyzed to predict the optimum seeding dates for central Arkansas (Table 4-10). The optimum seeding date range was defined as “seeding dates producing 95 to 100 percent yield potential.” Results suggest that the optimum time period for drill-seeded rice in most years, based solely on grain yields, in central Arkansas is March 23 to May 20 (Table 4-10). Growers must be cautioned that “risk factors” increase for very early seeding dates. These risk factors include, but are not limited to, stand reduction or failure, seedling stress and increased production costs. Management may overcome many of these risks and must be weighed against the potential benefits of early planting. For this reason, it is recommended that the optimum time for seeding rice be based on grain yield potential and management factors. Therefore, the estimated optimum seeding dates listed in Table 4-11, based on yield and management, are suggested for grower use. Relative yield, as affected by seeding date, is presented in Table 4-10 and should be used to make decisions concerning the profitability of late-seeded rice compared to alternate crops.

Table 4-10. Predicted relative yield potential for drill-seeded rice in central Arkansas by seeding date.

Relative Yield Potential	Actual Yield Potential†	Seeding Date Range††	
%	bu/A	Begin	Cut-off
95.0-100.0‡	166-175	March 23	May 20
90.0-94.9	158-165	May 21	June 1
85.0-89.9	149-157	June 2	June 11
80.0-84.9	140-148	June 11	June 18
70.0-79.9	123-139	June 19	June 30

† Actual yield potential is based on a 100% relative grain yield of 175 bu/A at 12% moisture.
‡ Considered optimum seeding date based on potential grain yield and does not consider other management risks or milling yield potential.
†† Seeding date and relative yield potential are based on a quadratic relationship described by the equation % relative yield = $22.4 + 1.33x - 0.006x^2$ (where x = Julian date or day number of year, where April 20 = day 110).

Source: Slaton et al. 1991.

Table 4-11. General suggested optimum and recommended seeding dates for south, central and north Arkansas geographic areas based on yield potential and management considerations.

Geographic Region	Optimum†		Recommended Absolute‡	
	Begin	Cut-off	Begin	Cut-off
South	March 28	May 20	March 20	June 15
Central	April 1	May 15	March 25	June 10
North	April 10	May 10	April 1	June 5

† Seeding during the optimum time frame does not guarantee high yields or suggest that crop failure cannot occur when rice is seeded during these times.
‡ Recommended absolute does NOT mean that a successful rice crop cannot be grown if seeded outside of the dates listed. Success may be evaluated and/or interpreted using various parameters (i.e., cropping systems, management, cash flow, field reclamation, etc.) and may differ among specific cultivars.

Specific cultivar recommendations for late-seeded rice (June seeding dates) should be made on yield performance in seeding date studies, seed availability and planned seeding date. Of the available cultivars that have been tested in seeding date studies, Diamond, Jupiter, Titan and Wells are recommended for late planting. The hybrids developed by RiceTec, Inc. also perform well when planted late. Contact your local county Extension agent or refer to the Cooperative Extension Service web page for the latest planting date study yield information.

If the estimated date of 50 percent heading is after September 10 to 20, rice should not be planted since cool temperatures and possible frost may significantly reduce grain yield and quality. The DD50 program, available at the county Extension office or online at https://dd50.uaex.edu/, can be used to estimate heading dates for different cultivars. A range of dates for the occurrence of freezing temperatures in several geographic regions is provided in Table 4-12. Table 4-13 lists the predicted dates for CL153, Diamond and RT XP753, emerged on April 1, May 1 and June 1, to reach 50 percent heading in northeast (Clay County), central (Prairie County) and southeast (Chicot County) Arkansas. Finally, seeding date may influence certain diseases. Therefore, disease susceptibility must be considered when selecting a cultivar for early or late seeding. For example, earlier seeded rice is less likely to suffer severe damage from blast, smuts or bacterial panicle blight diseases but may have increased sheath blight problems compared to late-seeded rice.

Tillage and Post-Seeding Management

In Arkansas, the most common method of seeding rice is direct, dry seeding using a drill, airplane or airflow truck. Broadcast seeding is most commonly used on clay soils or in wet years when speed of planting is important. Dry, broadcast-seeded rice is covered either by a final tillage operation or by flushing after levees are pulled. Dry seeding is practiced on about 94 percent of the Arkansas rice acreage. The remaining 6 percent is water-seeded rice.

The use of reduced tillage practices has increased in rice production over the past ten years. Reduced

Table 4-12. Expected freeze dates for several eastern Arkansas locations.

City - County	Last Date in Spring with Temp. < 32°F†	First Date in Fall with Temp < 32°F†
Corning - Clay‡	April 4 to April 17	October 11 to October 25
Augusta - Woodruff††	March 29 to April 14	October 19 to November 2
Pine Bluff - Jefferson‡	March 20 to April 3	October 26 to November 9
Crossett - Ashley‡	April 4 to April 16	October 22 to November 2

† Freeze dates were obtained from county soil surveys and are the dates for which temperatures below 32°F first or last occur in one to five out of every ten years.
‡ Time period from 1951 to 1974.
†† Time period from 1951 to 1990.

Table 4-13. Expected 50% heading dates of CL153, Diamond and RT XP753 rice cultivars in southeast, central and northeast Arkansas for three emergence dates.

		Predicted 50% Heading Date†		
Emergence Date	Cultivar	Chicot County	Prairie County	Clay County
April 1	CL153	July 6	July 15	July 19
	Diamond	July 6	July 16	July 20
	RT XP753	July 1	July 10	July 15
May 1	CL153	July 16	July 23	July 23
	Diamond	July 16	July 23	July 23
	RT XP753	July 11	July 18	July 18
June 1	CL153	August 8	August 13	August 13
	Diamond	August 9	August 14	August 14
	RT XP753	August 4	August 8	August 8

†Predictions are for 50% heading using the 30-year weather temperature means. Add 35 days for estimates of 20% grain moisture.

tillage practices may be more appropriately divided into two groups including stale seedbed (soil is tilled and floated in fall or late winter) or true no-till (rice is planted in previous crop stubble). A level seedbed free of potholes and excessive stubble or trash is desired, regardless of tillage and seeding method. A land plane or float is commonly used two times in conventional tillage operations to help eliminate small depressions and high spots in fields. Tillage practices implemented in conventional tilled fields may include a disk, field cultivator, roller and a land plane or float.

Management Key

Establish a smooth field surface that provides a good seedbed, drainage and water control.

Tillage requirements differ among soil textures, previous crop and field condition after previous crop harvest. An excellent seedbed can be prepared on most sandy and silt loam soils with minimal tillage. Tillage on clay soils usually produces a cloddy seedbed that does not provide good seed-to-soil contact. Stale seedbed or no-till seeding usually improves seed-to-soil contact on clay soils. The use of a roller before or behind the drill often improves seed-to-soil contact and speeds emergence by compacting the soil. This is best illustrated by field observations seen each spring where rice first emerges in truck or tractor tire tracks. Research has shown that rolling behind drilled or broadcast-seeded rice can increase stand population (Table 4-14).

Table 4-14. Influence of rolling behind drill on final rice stand density on a Perry clay soil at the Southeast Branch Experiment Station, located near Rohwer, Arkansas.

Cultivar	Rolled†	Non-rolled†
	Seedlings/ft^2	
Bond	21	17
Lemont	21	16

† Seeding rate was 40 seed/ft^2 for each cultivar.

Generally, levees should be surveyed on 0.2 foot vertical intervals for proper water management. However, if a field is very flat and a single levee may contain more than 10 acres, levees should be marked on 0.1 foot intervals to facilitate flooding. Rice fields having considerable slope may require that levees be surveyed on 0.3 to 0.4 foot intervals to reduce the number of levees. Levees may be surveyed and marked before or after seeding. Surveying levees in minimum tillage and no-till systems during the fall, winter or early spring spreads out labor requirements that are typically encountered following planting operations. Levee formation may be completed with two to eight passes with a levee disk, depending on soil texture. A couple of hours for drying may be required between levee disk passes for clay soils. On clay soils using reduced tillage practices, a levee base may be pulled after surveying in fall, winter or early spring to minimize water seepage losses.

Levee "squeezers" have been widely adopted and provide some benefits over a conventional levee disk. Barrow ditches are typically not as deep, resulting in better growth and production of rice in the barrow ditches. Levees are typically seeded on the final one to two passes with a levee disk that has a broadcast seeder. A levee gate should be installed in each levee by pushing out a section of soil in the direction of water flow. The ability to manage water is essential for all rice crop management practices. Construction of levees and gate installation should be performed as soon after planting as possible to enable flushing or flooding and to aid in stand establishment or pest management practices. Additional information on irrigation of rice will be covered in Chapter 10, Water Management.

Management Key

An accurate levee survey is critical to being able to manage water effectively and efficiently later in the season.

Rice harvest must be considered in planting and cultivar selection to ensure that rice matures over a range of dates and allows for timely harvest. Rice that is planted during a three-week period in April may mature and be ready for harvest at the same time. Rice can be planted much quicker than it can be harvested. Therefore, spread out planting dates to help spread out harvest.

Table 4-15 lists the estimated dates of 20 percent grain moisture for five cultivars that differ in maturity.

Table 4-15. **Influence of emergence date on predicted dates for 20% grain moisture for five cultivars using 30-year weather norms for Stuttgart, Arkansas.**

Cultivar	Rice Emergence Date				
	April 1	**April 15**	**May 1**	**May 15**	**June 1**
	Predicted Date for 20% Grain Moisture†				
CL153	August 14	August 15	August 22	September 2	September 15
Diamond	August 15	August 15	August 23	September 2	September 15
RT XP753	August 9	August 10	August 17	August 28	September 10
Jupiter	August 20	August 21	August 28	September 8	September 21
Titan	August 16	August 17	August 24	September 4	September 17

† Approximate date of 50% heading can be estimated by subtracting 35 days from listed date for CL153, Diamond, and RT XP753 or 45 days for Jupiter and Titan.

References

Counce, P.A. 1989. Row Spacing effects on rice yields. *Ark. Agric. Exp. Stn. Rep. Ser. 313*, Fayetteville.

Counce, P.A. 1987. Asymptotic and parabolic yield and linear nutrient content responses to rice population density.

Faw, W.F., and T.H. Johnston. 1975. Effect of seeding date on growth and performance of rice varieties in Arkansas. *Ark. Agric. Exp. Stn. Rep. Ser. 224*, Fayetteville.

Faw, W.F., and T.K. Porter. 1981. Effect of seeding rate on performance of rice varieties. *Ark. Agric. Exp. Stn. Rep. Ser. 287*, Fayetteville.

Frizzell, D.L., C.E. Wilson, Jr., R.J. Norman, N.A. Slaton, A.L. Richards, J.L. Hill, J.W. Branson, and S.K. Runsick. 2006. Influence of row spacing and seeding rate on rice grain yield. p. 270-275. In (R.J. Norman et al., (ed) *B.R. Wells Rice Research Studies 2005.* Ark. Agr. Exp. Sta. Res. Ser. 540.

Gravois, K.A., and R.S. Helms. 1998. Seeding date effect on rough rice yield and head rice and selection for stability. *Euphytica* 102:151-159

Jones, D.B., and G.H. Snyder. 1987. Seeding rate and row spacing effects on yield and yield components of drill-seeded rice. *Agron. J.* 79:623-626.

Runsick, S.K., C.E. Wilson, Jr., A.L. Richards, J.W. Branson, and J.L. Hill. 2006. Influence of seeding rate on grain yield and milling yield of five rice cultivars in Arkansas. p. 304-309 In (R.J. Norman et al., (ed) *B.R. Wells Rice Research Studies 2005.* Ark. Agr. Exp. Sta. Res. Ser. 540.

Slaton, N.A., R.S. Helms, H.M. Chaney, C.A. Stuart, and T.E. Windham. 1991. Results of the rice research verification trials, 1990. *AG94*-9-91. Univ. of Ark. Coop. Ext. Serv., Little Rock.

Chapter 5

Water-Seeded Rice

Jarrod Hardke and Bob Scott

Water-seeding rice is a common production method in southern Louisiana and areas in Texas and California. In Arkansas, water seeding usually accounts for less than 5 percent of total rice acres. The primary reasons for water-seeding are for red rice suppression, reduced labor and reduced inputs. Water-seeding can also aid in timely planting and reduce the risk of herbicide drift in areas where crops such as cotton are grown in close proximity to rice. Precision-leveling fields to zero grade has received increased interest due to decreased labor, ease of management, potentially less input costs and the ability to produce continuous rice.

Conventional Water-Seeding

Field Preparation

The primary objectives in field preparation are to destroy winter vegetation and reduce the chance of seedling drift. Water-seeding presents many new problems to rice farmers that are not common in dry-seeding rice. The following information is a general outline of water-seeding procedures. Following these guidelines should reduce the potential of stand loss, resulting in the need for replanting. A rough seedbed is essential. Leaving the soil ridged minimizes seedling drift. If drift occurs, there can be areas in the field with little or no rice seedlings, and replanting may be necessary. On clay soils, this can generally be accomplished with a disk and/or field cultivator. The field should be left with large clods (baseball size or smaller) to allow seeds an area to settle without being subject to drift. On silt loam soils, the ridges created by the field cultivator may dissolve due to water movement and leave the soil surface smooth. Therefore, this method is not recommended on silt loam soils. The recommended method of final seedbed preparation before flooding on both silt loam and clay soils is to use an implement called a groover. It is similar to a flat roller with angle iron rings on 6- to 8-inch centers. The groover forms small furrows in the seedbed, and the weight of the groover packs the soil, preventing the wave action of the water from smoothing the soil surface. Packing the soil also creates a level seedbed, which prevents high spots in the field where the soil may be exposed. Generally, high spots develop into areas that are heavily infested with weeds and/or red rice because of the lack of water coverage

Management Key

Begin with a rough seed bed through the use of a groover or through tillage and leave the surface cloddy on clay soils. The rough seedbed minimizes seedling drift.

The recommended seeding rate for water-seeded rice is 30 percent greater than for drill-seeded rice. Because in water-seeded rice the seed is on the soil surface, blackbird depredation tends to be more severe. Insects such as rice seed midge can also reduce rice stand density by feeding on the embryo as the seedling develops. Consult the RICESEED computer program for specific seeding rates for cultivars in water-seeded rice (Chapter 4, Rice Stand Establishment).

Methods of Presoaking

In water-seeding, the rice seed can be dry or pregerminated (presoaked). Pregerminated seed is highly recommended to enhance stand establishment and reduce risk of injury from rice seed midge. Pregerminated seeds are generally soaked for 24 to 36 hours, drained 24 to 48 hours and then flown into the flooded field. The duration of the drain period is dependent upon the air and water temperature. Under cool conditions (50°-60°F), seedling development is slow and a longer drain period may be necessary; however, in warmer conditions (greater than 65°F), a drain period of 24 hours or less is usually sufficient.

In general, when rice is pregerminated, about 50 percent of the seeds have the coleoptile emerging from the seed coat. This stage of seedling development is sometimes called 'pipping.' Rice seeds treated with gibberellic acid (Release or GibbGro) should not be used in water-seeded rice. Gibberellic acid promotes rapid shoot development which increases the risk for seedling drift.

When the rice is seeded dry, seeds are more likely to drift. If rice is presoaked, the heavy, wet seeds immediately fall into the grooves in the seedbed. **If Bolero herbicide is used preplant, seeds must be pre-soaked.** One problem farmers have is determining the best soaking method when pregerminating seed. Some farmers have built small grain bins which hold the seed and the water. After soaking and draining, the seeds are then augured into a truck prior to being flown into the water. Super (bulk) bags are often used to soak rice seed. The super bags are placed into a soak tank or pit. After soaking and draining, a boom is necessary to load the seed into the plane. Various other methods are commonly used by growers to soak seeds. Consult county Extension agents or other growers for more information on pregerminating seed.

Management Key

Use presoaked seed to minimize injury from rice seed midge and increase the potential for stand establishment.

Water Management

An adequate water supply is necessary for water-seeded rice. Fields should be small to ensure precise water management. Poor water management results in loss of both preplant nitrogen and red rice suppression. The methods of water management used in water-seeding rice are pinpoint and continuous flood. The pinpoint flood is recommended, especially if Bolero is used preplant. In pinpoint flooding, the water is drained to allow seedlings to anchor (peg down) their roots in the soil. The soil should not be allowed to crust (dry). Using the pinpoint flood method, you should be able to flood the field within five days and drain and reflood within three to five days for maximum red rice suppression. Thus, small fields approximately 40 acres in size are desirable for optimum water management. During the drain period, the seedling is exposed to oxygen, which promotes root growth for seedling anchorage. The drain period generally ranges from one to five days, depending upon soil type and weather conditions. The field should be reflooded with a shallow flood and the flood increased as the rice seedlings develop. With the continuous flood method, the water is maintained at a constant level and is never drained. Seedlings may take longer to peg down and be more susceptible to drift with this method. This method is best used on precision-leveled fields where a uniform, shallow flood can be maintained.

Management Key

Small fields are more effectively managed than larger fields when water seeding because of more precise water management ability.

Nutrient Management

A large percentage of the nitrogen required may be preplant incorporated in conventional water-seeded rice. However, no-till water-seeded rice presents very different challenges. Specific rates and nitrogen management practices for water-seeded rice are outlined in the Chapter 9, Soil Fertility.

Weed Control

Water-seeding rice is a cultural system that can be used to effectively reduce red rice. Water-seeding suppresses red rice and other grasses because the soil's oxygen is replaced with water once the field is flooded. **A rule of thumb is that grass or rice will emerge (germinate) either through soil or water but not both.** For the best red rice control, flood fields immediately after land preparation. This limits the amount of red rice seed that might germinate prior to flooding. The water-seeded system alone provides up to 75 percent red rice suppression when done properly. If herbicides such as Bolero are integrated into the system, red rice suppression may approach 90 percent.

If Bolero 8E (4 lbs ai per acre) is utilized, it should be applied after the field has been grooved. Bolero has activity on red rice, barnyardgrass, sprangletop and some aquatic weeds. After the surface application of Bolero, flood the field in preparation for planting. Refer to the herbicide label and MP44, *Recommended Chemicals for Weed and Brush Control*, for product use information. Some rice cultivars are sensitive to Bolero in the water-seeded system; therefore, these cultivars are not recommended for water seeding.

Command can be used in water-seeded rice. Application timing is pegging. Command used in this system will control grasses that may germinate during pegging of water-seeded rice.

The flooded environment changes the weed species that may cause problems in water-seeded fields. Weeds such as ducksalad, redstem, gooseweed, eclipta, dayflower and arrowhead are aquatic weeds that may be more severe problems in water-seeded rice. The herbicide Londax has good activity on most of these aquatic weeds. Londax should be applied after seedling rice has pegged down and the flood is stabilized as aquatic weeds are small and emerging. Londax should be applied at rates of 1 to 1.67 ounces per acre (product) for aquatic weed control. The best control is obtained when Londax is used before aquatic weeds become established or are just emerging. Alternative control measures for aquatic weeds include propanil, Regiment, Grasp, propanil tank mixed with Basagran, Strada or Grandstand after removing the flood or 2,4-D at mid-season. Be sure to read the herbicide label(s) since use guidelines for water-seeded rice may differ from those for dry-seeded rice.

Clearfield rice and the herbicides Newpath and Beyond can be effective tools for use in water-seeded rice. The main benefit of using Clearfield rice is red rice control. The main drawback to using Clearfield rice in water-seeded systems is that many of these systems are in continuous rice production. The safe plant-back interval of Newpath herbicide to regular rice cultivars is 18 months. Crop rotation to soybeans is recommended prior to planting conventional cultivars behind Newpath. Two applications of Newpath are required for season-long red rice control. In water-seeded rice there are fewer opportunities to make these applications. There is a statement on the Newpath label that says, "Do not apply in standing water"; this is due to a reduction in activity of Newpath. Therefore, opportunities to apply Newpath include burn-down, preflood and pegging. In addition, you can make a followup application of Beyond late POST-flood for controlling any escaped red rice.

In addition to red rice and other grass weeds, Newpath is the only in-crop herbicide that has been effective for suppression of rice cutgrass. Also, Beyond herbicide will effectively control ducksalad and suppress barnyardgrass later in the season.

Due to a heavy reliance on Permit, Newpath and other ALS-inhibiting herbicides over the past few years, a few populations of ALS-resistant annual sedges and yellow nutsedge have been identified. In addition, umbrella sedge is typically only found in zero-grade fields and cannot be effectively controlled with ALS herbicides. A good program approach for these sedge populations is to apply 3 quarts per acre of propanil and 3 pints per acre of Bolero early post-emergence (1-2 leaf) and then follow that later in the season with an application of propanil plus 1.5 pints per acre of Basagran. This program will typically provide 80 to 90 percent control of heavy sedge populations.

Insect Control

Rice water weevils can be a severe problem in water-seeded rice. The adult weevils are attracted to the open areas of water during early seedling development. Rice water weevil larvae cause damage to rice seedlings by pruning the root system. Root pruning occurs much earlier in water-seeded rice than in drill-seeded rice. Rice water weevils are attracted to the field earlier than in drill-seeded rice. Because the younger rice is flooded, more generations of rice water weevil larvae are likely, leading to longer time for feeding pressure compared to drill-seeded rice. In water-seeded rice, the larvae feed on less-developed roots of 2- to 3-leaf rice causing more severe injury early compared to tillering rice in drill-seeded culture. Preventative treatments are generally required to control rice water weevil in water-seeded rice. Treatment thresholds and treatment options are given in Chapter 12, Insect Management in Rice.

Management Key

Scout carefully for rice water weevil during the first 8 weeks after peg-down. Rice water weevil will be more severe in water-seeded rice than drill-seeded rice.

No-Till Water-Seeded Rice

While tillage does not influence many of the concerns for water-seeded rice, some specific circumstances should be considered when no-till water seeded rice is produced, particularly in continuous rice rotations.

Rice Stubble Management

One of the biggest challenges to producing continuous rice is managing the stubble from the previous crop. Obviously, in no-till systems, cultural practices must be worked out to prevent the stubble from interfering with the current crop. When the stubble is left in the field, decaying residue from the previous crop can cause production of organic compounds that are toxic to seedling rice. This happens regardless of whether the field is flooded in the winter or not. Therefore, the residue should be destroyed by tillage or burning. Since tillage is not desired, burning becomes the means to destroy the stubble. When a stripper header is used for harvest, the stubble will probably need to be cut and spread with a flail mower or equivalent. However, a conventional header with a good straw spreader will also prepare the field for an effective burn without the need for mowing.

Management Key

Burn the rice stubble in the fall for continuous, no-till rice fields to reduce the negative impacts on the next rice crop.

Nitrogen Management

Nitrogen management is a critical part of no-till water-seeded rice. The system does not allow efficient use of N fertilizer. Applications into the floodwater result in loss by ammonia volatilization. Preplant applications onto dry soil prior to flooding and seeding are not effective because the N is not incorporated. Many have found that multiple applications spread about 10 to 14 days apart are the most efficient means. However, this technique will usually result in as much as 25 percent more N fertilizer required compared to what would be needed in a dry-seeded field.

Chapter 6

DD50 Rice Management Program

Jarrod Hardke and Richard Norman

The DD50 program was developed in the 1970s to help rice farmers accurately time mid-season nitrogen (N) applications. The ability to predict growth stage, specifically internode elongation (IE), reduced physical labor required to sample fields to determine the accurate time for mid-season N application. Today, the DD50 continues to be used by Arkansas rice growers to time over 26 management decisions in rice production. Programs similar to the Arkansas DD50 have been developed in other Mid-South rice-producing states.

Midseason N application timing is no longer as important as it was 30 years ago due to development of shorter season, stiff-strawed cultivars. Optimum grain yield for currently-produced cultivars requires more preflood N and is less dependent on midseason N. However, the DD50 remains a vital program and source of information for pest management, timing of N, and overall production of new varieties.

The DD50 is a modification of the growing degree-day concept, which uses temperature data to predict rice development. The growing degree-day

Table 6-1. Grower participation in the DD50 computer rice management program.

Year	Producers	Fields	Acres	% of Total Acres	Year	Producers	Fields	Acres	% of Total Acres
	number participating					number participating			
1978	540	N/A	N/A	N/A	1998	2,069	11,287	800,851	53.9
1979	1,320	3,456	237,362	23.3	1999	1,925	11,458	805,199	49.6
1980	1,620	4,285	240,000	18.8	2000	1,710	9,946	690,504	49.0
1981	2,000	6,166	472,148	30.7	2001	1,859	11,774	814,038	50.2
1982	2,150	7,595	528,796	39.8	2002	1,809	10,468	716,567	47.6
1983	2,110	6,549	396,417	43.3	2003	1,552	9,562	673,693	46.3
1984	2,563	8,161	536,194	46.6	2004	1,552	9,393	672,490	43.3
1985	2,723	10,053	650,201	61.9	2005	1,337	9,112	648,870	39.7
1986	2,769	12,233	803,121	78.7	2006	1,252	7,753	339,051	40.2
1987	2,746	8,887	547,904	54.2	2007	1,066	6,564	493,508	37.2
1988	2,711	10,359	644,754	53.3	2008	1,000	6,079	432,860	31.1
1989	2,775	9,760	646,470	56.7	2009	988	6,160	451,070	30.5
1990	2,668	11,250	695,897	58.0	2010	1,039	7,158	533,307	30.3
1991	2,695	11,679	753,282	59.8	2011	602	3,723	257,067	22.7
1992	2,522	12,096	816,643	59.2	2012	655	4,145	331,099	26.7
1993	2,326	10,945	689,447	56.1	2013	600	3,482	260,567	24.4
1994	2,537	13,273	872,330	61.4	2014	660	4,498	337,725	22.9
1995	2,580	13,028	871,743	65.1	2015	487	3,164	254,235	19.8
1996	2,084	10,349	741,794	63.4	2016	528	3,609	300,676	19.8
1997	2,107	11,441	784,966	56.5	2017	415	2,651	212,527	19.4

concept is a measure of a day's thermal quality for plant growth based on air temperature. Equation 1 is used to calculate a day's thermal growing quality. The Arkansas program uses a maximum of 32 growing degree units that may be accumulated in a single day. Daily low and high temperatures are used to account for the fact that temperatures above these thresholds do not significantly increase the speed of plant development.

Weather data is collected at over 30 sites across Arkansas. To account for weather differences among geographic locations, DD50 predictions are calculated based on temperature data collected from locations closest to the specific fields based on the county selected for the field.

The DD50 program accounts for cool temperatures that may delay development during seedling growth for early-seeded rice (emerging before May 1) by adding 50 DD50 units to thresholds up to ½-inch internode elongation. The final adjustment made by the DD50 is to add 5 days between the normal predicted dates for 50% heading and 20% grain moisture to account for slower moisture loss from rice panicles for rice that heads after September 1.

Equation 1

$$\text{DD50} = \frac{\text{Daily Maximum Temp} + \text{Daily Minimum Temp}}{2} - 50$$

Maximum temperature = 94°F if maximum temperature is >94°F.
Minimum temperature = 70°F if minimum temperature is >70°F.

How to Use the DD50

The Rice DD50 program can be used by individual producers who manage their own crops, by consultants with multiple clients, or by county agents for producers within their county. To participate in the DD50 rice management program, two options are available to producers or consultants. The first option is for producers or consultants to log onto the Cooperative Extension Service website and enter their fields directly at http://DD50.uaex.edu/. The second option is for producers to submit their cultivar, acreage, and emergence date information of each rice field to their local county Extension office to enter into the program and send the report to the producer. It is preferred that producers and consultants set up an account and enter their own fields so that they may check the program for updates as the season and the program information progress. An online DD50 User's Guide is available to individuals who access the program through the internet.

Emergence is defined as the time 8 or more plants per square foot for varieties or 4 or more plants per square foot for hybrids (seedlings less than 1 inch tall) have emerged from the soil for dry-seeded rice. In dry-seeded rice, DD50 accumulation begins the day plants first emerge from the soil. The coleoptile (shoot) has a white tip upon emergence before photosynthesis begins to produce chlorophyll (green color). In water-seeded rice, emergence is defined as the time when plants have shoot lengths of ½ to ¾ inch.

Establishing an emergence date can be difficult in the case of uneven emergence. In this situation, record the date at which a sufficient number of plants have emerged to ensure that replanting is not required. If rice emerged at two distinct times in separate areas within a field, rather than average the two dates, submit dates for each emergence time. It may be necessary to manage the two areas of the field separately if emergence dates differ greatly.

At the beginning of the season, the DD50 operates using 30-year temperature averages. The DD50 is continually updated with the current year's weather data to improve accuracy. Average daily temperatures and resulting cumulative heat units vary considerably across years. Those with enrolled fields will be notified when current year temperature data significantly differs from the predictions based on 30-year average temperature data. In general, the events predicted by the DD50 should be accurate within plus or minus two days for dry-seeded rice.

The accuracy of the DD50 is influenced by management practices and variations of weather within each zone. For example, delaying the flood or preflood N, overfertilization, herbicide injury and/or nutritional deficiencies may slow rice development, resulting in the DD50 predicted dates occurring later than actual plant development. Water-seeded rice often develops at a faster rate than dry-seeded rice because the floodwater buffers the effect of air temperature extremes. The accuracy of the DD50 is also dependent on use of the correct emergence date, cultivar name, and uniformity of stand. The DD50 program is not intended as a substitute for scouting fields but rather a set of guidelines to assist growers with management decisions. Therefore, growers are

Table 6-2. DD50 accumulations from recent years compared to the 30-year average accumulation at Stuttgart, Arkansas.

Date	30-Year Mean	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	cumulative heat units										
March 16-31	113	53	251	105	108	59	89	292	50	46	130
April 1-15	161	228	80	123	86	239	230	243	142	136	256
April 16-30	226	297	201	188	265	232	252	220	211	214	221
May 1-15	285	248	371	244	268	338	254	349	209	292	323
May 16-31	377	414	359	384	338	420	347	432	393	355	366
June 1-15	408	410	427	458	399	471	476	378	398	396	403
June 16-30	441	439	457	436	476	471	466	453	452	433	458
July 1-15	447	447	430	446	450	464	465	455	399	423	423

encouraged to manually check the plant growth stage before making management decisions where growth stage is extremely important.

Uses of the DD50

Today the DD50 program assists growers with 26 management decisions based on growth stage, including herbicide application, critical times to scout and spray for insects and diseases, and N application. The DD50 program is a very important tool for farmers growing new cultivars. Rice cultivars of differing maturity emerging on the same day differ in the rate of physiological development throughout the season. In general, cultivars do not differ in the amount of time required to reach the 4- to 5-leaf stage. The time required from 50% heading to physiological maturity or harvest moisture is also assumed to be constant among grain types. Long-, medium- and short-grain cultivars are allowed 35, 40, and 50 days, respectively, from 50% heading to 20% grain moisture for flowering, ripening (grain fill), and moisture loss from grains. The time (date) of heading, kernel characteristics, canopy structure, and precipitation can influence the time required for grain to reach 20% moisture. The major difference in growth among cultivars occurs either between the 4- to 5-leaf stage and ½-inch IE or ½-inch IE and 50 % heading stages. Farmers are encouraged to use the DD50 to help plan rice seeding and harvest dates of different cultivars.

Table 6-3. Days required for ten rice cultivars, emerged on May 1, to reach specific growth stages.

Cultivar	Growth Stage 4-Leaf	½" IE	50% Heading	20% Moisture
	cumulative days to reach growth stages†			
CL151	19	48 (29)	76 (28)	111 (35)
CL153	19	49 (30)	80 (31)	115 (35)
CL172	19	53 (34)	81 (28)	116 (35)
Diamond	19	53 (34)	80 (27)	115 (35)
LaKast	19	53 (34)	78 (25)	113 (35)
Roy J	19	56 (37)	86 (30)	121 (35)
RT CLXL745	19	50 (31)	76 (26)	111 (35)
RT XP753	19	48 (29)	76 (28)	111 (35)
Jupiter	19	58 (39)	81 (23)	121 (40)
Titan	19	54 (35)	78 (24)	118 (40)

† Days between growth stages in parentheses.

The DD50 program is also a useful tool in predicting peak harvest periods for grain elevator operators and farmers. Farmers can use the DD50 to coordinate planting and harvest schedules based on cultivar and expected emergence dates. In addition, state and county information concerning cultivar acreage and percentage of rice at critical development stages are summarized by the DD50 program, providing invaluable information on Arkansas rice production.

Explanation of the DD50 Printout

The DD50 provides predicted dates for timing 26 management practices. The following is an explanation for each management practice and the predicted dates. The date or range of dates predicted for each procedure should be used as a guideline. Since factors other than temperature can influence the rate of rice development, farmers/consultants should check each field in random spots to ensure DD50 accuracy. The listing of a pesticide application window does not always mean that the pesticide is recommended by the University of Arkansas System Division of Agriculture or that these products are recommended over other suitable alternatives. Suggested timing for pesticides on the DD50 assumes federal and state labeling. However, label revisions can occur at any time. Before using any pesticide, always read and follow the directions and precautions printed on the label. Refer to MP44, Recommended Chemicals for Weed and Brush Control, for specific recommendations.

Growth Stages

Beginning and Optimum Tillering, Apply Early/Preflood – Predicted dates indicate the best time to apply early nitrogen to stimulate tiller formation. Tillering begins at the 4- to 5-leaf growth stage. An ammonium N source should be applied to a dry soil and flooded immediately. The timeframe of early N application is the predicted dates for which 350 to 550 DD50 units have accumulated

Final Recommended Time to Apply Preflood N if Early N is Delayed – Early preflood N applications are often delayed by wet soil conditions during the above optimum recommended dates. Research has shown that early or preflood N may be delayed by several weeks without a loss of grain yield. If wet soil conditions persist, growers should apply N to the moist soil by this predicted date and attempt to let the soil dry, but flood immediately if additional wetting occurs. This date is 510 DD50 units in length or about three weeks before the predicted time of ½-inch IE, depending on cultivar. This provides about three weeks for plant uptake of fertilizer N before panicle differentiation (½-inch IE) occurs. For cultivars with a relatively short vegetative growth period, such as Cocodrie, this predicted time occurs very soon after the predicted time for beginning and optimum tillering. Therefore, ½-inch IE may occur sooner than three weeks after flooding.

Beginning Internode Elongation (BIE) – This corresponds to the time to begin checking for joint (internode) movement. Beginning IE corresponds approximately to the green ring stage or panicle initiation and signifies the change from vegetative to reproductive growth. This is also the time when the midseason N fertilizer application window begins. Although the timing of BIE differs among varieties, the DD50 uses 210 DD50 units or about 7 days before ½-inch IE as the predicted date

½ inch IE – This is the growth stage corresponding to panicle differentiation (PD) when panicles are about 2 millimeters long and separation between nodes is ½-inch. This is the first growth stage DD50 accuracy can be visually checked. This growth stage is measured for all cultivars included in the DD50 program in replicated research trials over a range of seeding dates to establish the mean number of accumulated DD50 units required to reach ½-inch IE. Management practices such as time of N fertilizer application, emergence date, time of flooding, other nutritional factors, temperature, and pesticide applications can affect the accuracy of this predicted date.

50% Heading – This is the growth stage when 50 percent of the panicles have partially emerged from the boot. This is the second growth stage DD50 accuracy can be visually checked. Accuracy and threshold development are similar to that described for ½-inch IE.

Drain Date – A date to drain the field in preparation for harvest is provided. Pumping may be ceased about 10 to 14 days earlier provided there is adequate water on the field to prevent drought stress which could reduce grain yield and milling quality in some years. Consider soil type, weather conditions, and maturity differences within the field when ceasing pumping and draining for harvest. The listed time is based on 25, 30, and 40 calendar days after 50% heading for long, medium, and short grain cultivars, respectively. Drain dates are delayed an additional 5 days for rice heading after September 1.

20% Grain Moisture – The approximate date that grain will be at 20 percent moisture and ready for harvest is provided. Actual grain moisture and harvest date may vary 5 to 10 days, depending on weather conditions, management, cultivar, and stand uniformity. This time is based on 35, 40, and 50 calendar days after 50% heading for long, medium, and short grain cultivars, respectively. Predicted 20% grain moisture dates are delayed an additional 5 days for rice heading after September 1. Actual time that grain reaches 20% moisture may be plus or minus 5 days of that predicted.

Herbicides

Aim or Grandstand-R – Aim or Grandstand can beapplied to rice from the 2-to-3-leaf growth stage up to the ½-inch IE growth stage. To avoid injury, do not apply after ½-inch IE. For water-seeded rice, Grandstand cannot be applied until rice has reached the 3- to 4-leaf stage. The beginning date listed on the DD50 is for the 2-to 3-leaf stage as labeled for dry-seeded rice.

Beyond – The preferred cutoff date for Beyond occurs at BIE for Clearfield hybrids and BIE+14 days for Clearfield varieties. DO NOT apply Beyond to non-Clearfield cultivars. Beyond can be applied to Clearfield rice only following at least one application of Newpath or Clearpath herbicides.

Blazer + Propanil Tank Mix – The safe dates to apply Blazer tank mixed with Propanil. Blazer may antagonize Propanil activity. This timeframe begins at the 3-leaf growth stage for Blazer and ends with the cut-off date for Propanil, which is at the end of tillering. When applied alone, Blazer cannot be applied after the boot stage.

Blazer or LockDown – LockDown is a biological herbicide (fungus) specifically used to control northern jointvetch (curly indigo). LockDown is not compatible with many pesticides. The LockDown label recommends against tank mixes of LockDown and other herbicides (including Blazer), insecticides, fungicides, and liquid nitrogen fertilizers. Best activity will be obtained under high humidity and flooded field conditions. Apply before northern jointvetch flowers. This timeframe is also the recommended time for application of Blazer (alone) for coffeebean control. The timeframe begins 400 DD50 units before ½-inch IE and ends 15 days (450 DD50 units) before 50% heading as specified by the Blazer label. LockDown may actually be applied until rice begins to head. LockDown application during the predicted time allows adequate time for control of northern jointvetch.

Grasp – The preferred cutoff date, which is based on the 60-day pre-harvest interval (PHI) as required on the herbicide label. This is calculated back from the date of 20% grain moisture.

Londax – The application window for Londax begins at the 1-leaf stage and ends with the 60-day pre-harvest interval (PHI). Apply Londax and Propanil for yellow nutsedge control within 10 days prior to flood establishment. For aquatic weed control, apply in the static flood when aquatics are emerging for best control.

Permit – The preferred cutoff date, which is based on the 48-day pre-harvest interval (PHI) as required on the herbicide label. This is calculated back from the date of 20% grain moisture.

Phenoxys, 2,4-D – The safe dates to apply 2,4-D or MCPA are indicated on the DD50 report. Maximum IE should not exceed ½-inch. Apply midseason N within five days after phenoxy application to aid in plant recovery. The window for application length depends on rice cultivar.

Propanil – The preferred cutoff date occurs at BIE. Injury may occur if applied after the cutoff date. The labeled cutoff restriction for Propanil is at the end of tillering.

Provisia – The safe dates to apply Provisia herbicide to tolerant rice cultivars are indicated on the DD50 report. Provisia herbicide can be applied to Provisia rice cultivars from the 1-leaf growth stage up to the BIE growth stage. To avoid potential injury, do not apply Provisia after panicle initiation (BIE). DO NOT apply Provisia herbicide to non-Provisia cultivars.

Regiment – Regiment can be applied to rice from the 3-leaf growth stage up to the BIE growth stage. To avoid injury, do not apply Regiment until the 3rd leaf is fully expanded and do not apply after panicle initiation (BIE).

Ricestar – Ricestar can be applied to rice from the 1-leaf growth stage up to the BIE growth stage. To avoid potential injury, do not apply Ricestar after panicle initiation (BIE).

Other

Rice Water Weevil (RWW) Alert – A date range is not provided for rice water weevil management due to differences in flood management of specific fields. Instead, it is included as a note to remind of the critical timing to scout for rice water weevil leaf scars. Begin scouting flooded rice fields for adult leaf feeding scars the first 7 days after flooding for dry-seeded rice. If warranted, insecticide applications must be made 7-10 days after flood establishment for rice water weevil control.

Straighthead – The 10- to 14-day period to have rice fields dried (stressed) for straighthead prevention is provided. The first date is NOT a drain date. Drain in sufficient time to allow for adequate drought stress on rice during the predicted timeframe and reestablish a flood before ½-inch IE. Notice the short interval between early N application and the straighthead control period for very-short-season cultivars, like Cocodrie. Cultivars that are highly susceptible to straighthead are given 400 DD50 units (about 14 days) for drying. Cultivars less susceptible to straighthead are given a 10-day window (300 DD50 units). Cultivar susceptibility ratings are noted on the DD50 report.

Midseason N – The time to apply midseason N (if required) should be made after BIE and at least 3 weeks after the preflood N has been incorporated by the flood. This window begins 1 day after predicted BIE. It is recommended that midseason N be applied in a single application. Recent research shows that rice response to midseason N is equal if applied from BIE to 21 days after BIE as long as it has been at least 21 days since the preflood N was incorporated by the flood. When rice is very N deficient at midseason a second application may be desirable and should be made 7 days after the initial application.

Apply Boot N – The RiceTec hybrids have a recommendation for an N application at the boot to late boot growth stage. The predicted time for this application is 390 DD50 units in length and begins about 17 days prior to 50% heading and ends at 50% heading. Other cultivars may also benefit from boot N applications if midseason N was not managed properly.

Sheath Blight – Begin scouting for sheath blight at BIE and stop prior to 50% heading during the dates provided. Length of the scouting period depends on cultivar maturity. Treatment before ½-inch IE and after the last predicted date is not recommended. Cultivar susceptibility ratings are noted on the DD50 report.

Apply Tilt for Kernel Smut Prevention – The fungicide Tilt or other propiconazole-containing products should be applied in this window for prevention of kernel smut on very susceptible or susceptible cultivars. Cultivars rated as moderately susceptible to tolerant will have a "Not Recommended" statement instead of application dates. The decision to apply Tilt for kernel smut prevention should be based on cultivar susceptibility, marketing, and field history. This timeframe is strictly for prevention since kernel smut cannot be scouted for prior to heading. The labeled cut-off date for Tilt application is late boot or beginning of panicle emergence from the boot. The predicted time is 390 DD50 units in length and begins about 17 days before 50% heading and ends about 4 days before 50% heading. Fungicide applications for kernel smut are recommended for AB647, Cheniere, CL111, CL151, CL153, Cocodrie, Diamond, Francis, Jazzman-2, LaKast, Mermentau, Rex, RT 7311 CL, RT CLXL745, Roy J, Taggart and Wells.

Apply Tilt for False Smut Prevention – The fungicide Tilt or other propiconazole-containing products should be applied in this window for prevention of false smut on very susceptible cultivars; and if conditions favor, cultivars that are susceptible. The decision to apply Tilt for false smut prevention should be based on cultivar susceptibility, marketing, and field history. This timeframe is strictly for prevention since false smut cannot be scouted for prior to heading. The labeled cut-off date for Tilt application is late boot or beginning of panicle emergence from the boot. The predicted time is 390 DD50 units in length and begins about 17 days before 50% heading and ends about 4 days before 50% heading. Fungicide applications for false smut are recommended for Diamond, PVL01, RT Gemini 214 CL, RT XP760 and Thad. Application is recommended for most other cultivars only if conditions favor.

Blast – The first time listed to scout for blast symptoms is the critical period to determine if blast is present and plan for treatment. The first critical stage should coincide with the late boot stage about 200 DD50 units before 50% heading. If foliar blast lesions have been detected, this is the approximate time for the first fungicide application to protect the emerging panicle. Rice should be about 10% headed for the timing of the first fungicide application. The second critical stage should coincide with about 75% panicle emergence from the boot, but the panicle base (neck) must still be in the boot. Fields should be scouted for blast during the entire season. Cultivar susceptibility ratings are noted on the DD50 report.

Stink Bugs – The period to begin scouting for rice stink bugs by sweep net begins immediately after 50% eading and continues until at least 60% of kernels have reached the hard dough stage (kernels are straw-colored). Treat if threshold populations are found during this time. Threshold is 5 stink bugs per 10 sweeps the first two weeks of heading and 10 per 10 sweeps the second two weeks of heading.

HARDKE HANDBOOK	5/10/2018 3:08:26 PM
RREC	*County: Arkansas*
Stuttgart, AR 72160	*Cultivar: Diamond*
Field: Diamond	*Weather Zone: 101*
Emergence Date: 5/1/2018	

Apply Early / Preflood N (Beginning – Optimum Tillering)	**5/17/2018 - 5/25/2018**
Final recommended time to apply preflood N if early N delayed	**6/4/2018**
Rice Water Weevil Alert: Scout for Rice Water Weevil leaf scarring the first 7 days after flooding. Timing is critical (see MP144).	
Diamond has no rating for straighthead, have soil dry between:	**6/3/2018 - 6/17/2018**
Beginning internode elongation (green ring):	**6/15/2018**
1/2-inch internode elongation:	**6/21/2018**
Apply midseason N to varieties after Make application AFTER beginning internode elongation AND at least 3 weeks after preflood N incorporated by flood.	**6/16/2018**
Scout for sheath blight: (Diamond is rated susceptible to sheath blight.)	**6/15/2018 - 7/15/2018**
Apply boot N to hybrids	**NOT Recommended**
Apply Tilt for kernel smut prevention (see MP192) (Diamond is rated susceptible to kernel smut.) Treatment Recommended.	**7/2/2018 - 7/15/2018**
Apply Tilt for false smut prevention (see MP192) (Diamond is rated very susceptible to FALSE smut.) Treatment Recommended.	**7/2/2018 - 7/15/2018**
Critical scouting time for blast symptoms.(see MP192) (Diamond is rated susceptible to blast.)	**6/15/2018 - 7/21/2018**
1st critical stage for neck blast fungicide application:	**7/12/2018**
2nd critical stage for neck blast fungicide application:	**7/21/2018**
Scout for rice stink bug between:	**7/20/2018 - 8/23/2018**
50% Heading:	**7/19/2018**
Drain field: Consider approximate date and grain maturity (2/3 straw colored kernels on loam soil and 1/2 straw colored kernels on clay soil).	**8/13/2018**
Approximate time of 20% grain moisture	**8/23/2018**

Herbicide Application Information

Apply Ricestar Between	**5/8/2018 - 6/15/2018**
Apply Provisia between	**NOT recommended**
Apply Regiment Between	**5/12/2018 - 6/15/2018**
Apply AIM or Grandstand - R between	**5/12/2018 - 6/21/2018**
Apply Blazer + Propanil between	**5/12/2018 - 6/15/2018**
Apply Londax between	**5/8/2018 - 6/24/2018**

Apply Blazer or Lockdown for coffeebean/NJV control	**6/8/2018 - 7/4/2018**
Propanil cut-off date	**6/15/2018**
Beyond cut-off date:	**NOT recommended**
Apply Phenoxy (2,4 - D) between	**6/11/2018 - 6/21/2018**
Grasp cut-off date	**6/24/2018**
Permit cut-off date	**7/6/2018**

Produced by the University of Arkansas System Division of Agriculture and the Arkansas Rice Research and Promotion Board. Weather data supplied by the NOAA Regional Climate Centers.

Chapter

7

Rice Weed Control

Bob Scott, Jason Norsworthy, Tom Barber and Jarrod Hardke

Weeds compete with rice for sunlight, nutrients and water and, when not controlled, reduce yield. In addition to competitive yield loss, weed seeds can reduce rice quality and grade. Economic losses from quality and grade reductions are usually quantified at the mill, but competitive losses may go unnoticed when scattered weeds are left uncontrolled for the duration of the production season. Secondary effects of weeds are numerous and include reduced harvesting and processing efficiency, increased insect and disease severity and increased production costs, as well as increased soil seedbank which produces even more weeds in future crops and contributes to the development of herbicide-resistant weeds. Weed control costs in Rice Research Verification Program (RRVP) fields between 2006 and 2012 averaged $68.91 per acre. During this same time period, the number of herbicide applications, including burndown, in the RRVP has ranged from 1.6 to 2.2 per acre per year, with an overall average of 2.0 per acre per year. Custom application of herbicides typically represents nearly 15 to 20 percent of the costs associated with weed control. Arkansas rice growers spend an estimated $100 million each year on weed control alone.

Effective management of weeds requires an understanding of how and when they compete with rice. Weeds vary in their competitive effects with rice (Table 7-1). In weed competition studies, rice grain yield reductions have ranged from 82 percent with red rice to 10 percent with eclipta. Factors that influence yield loss from weed competition include weed species, duration of competition, weed density, rice cultivar characteristics and other cultural management dynamics that influence rice growth. The influence of rice cultivar in fields with a history of high weed density, especially red rice, is often overlooked. Semi-dwarf or short rice cultivars generally have greater yield losses from weed competition compared to taller rice cultivars. The ability of a cultivar to tiller and its canopy architecture (erect or horizontal leaves) may also influence its ability to compete with weeds. For example, Lemont (semi-dwarf) yields were reduced by 17 percent by red rice densities of 8,100 red rice plants per acre. In comparison, Newbonnet (short-statured) yields were decreased by only 7 percent by the same red rice population. In more recent studies, more aggressively tillering, taller rice cultivars such as XL8 competed better with red rice than conventional rice cultivars (Table 7-2).

Table 7-1. **Rice yield loss from heavy, season-long weed interference.**

Weed Species	Potential Yield Loss	Critical Time to Control to Avoid Yield Loss
	%	
Red rice	82	mid-season
Barnyardgrass	70	early season
Bearded sprangletop	36	early season
Amazon sprangletop	35	early season
Broadleaf signalgrass	32	early season
Annual sedge	50	early season
Ducksalad	21	mid-season
Hemp sesbania	19	mid-season
Spreading dayflower	18	mid-season
Northern jointvetch	17	mid-season
Eclipta	10	mid-season

Source: R.J. Smith, Jr. 1988. *Weed Technology*. 2:232-241.

Table 7-2. Red rice density (plants/m^2) at 12 weeks after emergence†.

Variety/Hybrid	Red Rice Seeding Rate			
	2.4	3.6	6.0	12.0
	plants/m^2			
CL161	1.12	1.35	2.78	4.44
Cocodrie	1.22	1.54	2.41	4.06
Lagrue	0.87	1.44	2.41	3.71
Lemont	1.44	2.14	2.92	4.67
XL8	1.00	1.47	2.12	3.41
LSD $_{(0.05)}$	0.46			

† 1 m^2 is approximately 1 yd^2.

Source: Ottis, B.V., K.L. Smith, R.C. Scott and R.E. Talbert. 2005. *Weed Sci.* 53:499-504.

Research on the duration of weed competition has provided information on when each weed species competes with rice. Table 7-1 lists the critical time that several weeds should be controlled to avoid yield losses. Most grass weeds, except red rice, are highly competitive with rice early in the growing season and should be controlled shortly after emergence. For example, barnyardgrass grows faster and develops more biomass than rice during the early season, which gives it a competitive advantage. Red rice and most broadleaf weeds compete with rice later in the season and thus can be controlled later in the season without significant yield losses.

Weed thresholds have been established from weed density and duration studies to serve as a guide for determining the need for an herbicide application. In rice fields, there are generally multiple weed species that can potentially reduce rice yield and quality. Correct seedling weed identification in the field is critical for proper herbicide selection.

Herbicide Resistance Management

Resistance to several rice herbicides, including Facet, Londax, Newpath, Grasp, Regiment, Command, Permit and propanil, has been documented. In addition, barnyardgrass with multiple resistance to Newpath, Facet and propanil has now been identified. Options for control of this barnyardgrass include Bolero, Prowl, Command, Ricestar and Clincher. Research has shown that the risk of barnyardgrass developing resistance to ALS herbicides increases substantially in the absence of Command. Field research also shows that there are fewer barnyardgrass escapes at harvest in Clearfield rice if the season starts with a Command application. Rice flatsedge, smallflower umbrella sedge and yellow nutsedge have developed resistance to the ALS herbicides (Permit, Regiment, Grasp, etc.). Over the past few years, the occurrence of ALS-resistant sedges has been on the increase.

Following the introduction of Clearfield rice, outcrossing of the imadazolinone-resistant gene into red rice has also been documented. This outcrossing between Clearfield rice and red rice creates red rice offspring that are resistant to Newpath herbicide. Red rice resistant to Newpath and other herbicides with the same mode of action seriously jeopardizes the Clearfield technology. Widespread distribution of resistant red rice would nullify the benefits of Clearfield and destroy the only effective means of controlling this serious weed pest. Prevention of weed resistance to herbicides can be managed by strict adherence to rotation of herbicide chemistry (mode of action) and crops grown in the rotation. See the herbicide resistance section of MP44 (*Recommended Chemicals for Weed and Brush Control in Arkansas*) for additional information.

Clearfield Rice

Clearfield rice was introduced into the market in 2002. This nontransgenic rice was developed to be tolerant to the imadazolinone family of herbicides. Newpath and Beyond herbicides were developed for use in Clearfield rice. Clearpath is a premix of Newpath and Facet herbicides. While Newpath controls many grass and broadleaf weeds in rice, the primary use of the Clearfield system is for red rice and barnyardgrass control. Newpath herbicide is only labeled for use on Clearfield rice cultivars, usually designated with "CL" in the cultivar name, such as CL111, CL151, CL153, CL163, CL172, RT 7311 CL, RT CLXL745 and RT Gemini 214 CL. With the exception of the hybrids, Clearfield rice cultivars may yield less than modern conventional cultivars. This may limit the "fit" for this system to red rice acres or acres with other specific weed control issues until higher yielding cultivars are released. In many cases, these weed control issues may result in CL cultivars actually yielding the most, due to lack of weed control in conventional rice.

Newpath herbicide provides both residual and contact control of weeds. Newpath should be applied twice at 4 ounces per acre for effective red rice control and control of other grass weeds. Sequential Newpath systems can be applied either 4 ounces per acre preplant incorporated or preemergence, followed by 4 ounces per acre early post or in two 4-ounce per acre post applications. In sequential post applications, the first application of Newpath should be applied to 1- to 2-leaf red rice or other grass weeds. It is beneficial and recommended that a good preemergence herbicide, such as Command, be applied after planting to control other grass weeds and help prevent resistance. The label allows up to 12 ounces per acre applied in two 6-ounce per acre applications for extremely heavy red rice infestation but is not allowed on the hybrids due to injury potential (See MP44 for specific weed and timing options.)

Newpath herbicide is not effective for jointvetch, hemp sesbania or eclipta control. Newpath should be applied in a tank-mix with a herbicide that will effectively control these weeds.

Newpath is a long-residual herbicide and persists in the soil from one year to the next. Crop safety concerns dictate that conventional rice not be planted the year following Newpath applications. Red rice resistant management requires that Clearfield rice not be planted in consecutive years. For these reasons, soybeans are usually grown in rotation with Clearfield rice. In this rotation, glyphosate or a graminicide such as Select, Assure II or Poast Plus should be used for red rice control. This rotational system will help prevent herbicide resistance from developing.

Provisia Rice

Provisia rice was introduced in 2018. This non-transgenic rice was developed to tolerate a specific group of herbicides in the graminicide (or ACCase inhibitors) group 1 class of chemistry. Other rice herbicides in this group include RiceStar HT and Clincher. Provisia herbicide contains the active ingredient quizalofop. Other members of the graminicide family not labeled for rice will cause severe injury to Provisia rice. The use rate for Provisia will be 15.5 fluid ounces of product per year, with no more than two applications per season. Single applications of Provisia will control many small annual grasses when applied early postemergence under favorable environmental conditions. However, two applications will be required for larger grass and for complete control of weedy rice, including ALS- or CL-resistant weedy rice biotypes. Many tank mixtures with Provisia will cause antagonism. It is recommended that broadleaf herbicides be tank-mixed only in the first of two sequential applications. Avoid tank mixtures with Grandstand, propanil and 2,4-D. Always use a crop oil concentrate with Provisia herbicide. A good residual program like Command plus League or similar will make POST grass control with Provisia easier and more effective. Care should be taken not to drift Provisia onto conventional/Clearfield rice, corn, sorghum and other desirable grass species. Provisia herbicide will not damage soybean.

Grass Weed Control

Barnyardgrass is the most common grass weed in rice. Barnyardgrass and other grass weeds (sprangletop and broadleaf signalgrass) must be controlled soon after emergence to prevent yield loss. Once a permanent flood is established, these grassy weeds usually will not emerge.

Herbicides to control grass weeds include Bolero, Clincher, Command, Facet, Regiment, Grasp, propanil, Prowl and Ricestar HT. Herbicide selection for grass weed control should be specific for each situation. The weed response rating table (Table 7-3, next page) indicates the spectrum of activity for these herbicides applied alone or in tank-mixed combinations. The following is a brief review of several herbicides that can be used for grass control in dry-seeded rice. ***The statements included in this chapter do not imply endorsement of any product and do not substitute for labeled herbicide restrictions. Herbicide use information on labels often changes, and labels should always be checked prior to use.***

Propanil (Superwham, RiceShot, etc.)

Propanil has been the primary herbicide used for rice weed control for over 40 years. Propanil is a contact herbicide and, when used alone, generally requires a second application before the permanent flood is established for complete grass control. Good spray coverage with weed foliage is important for successful control. Weed foliage must not be covered with water at time of application. Propanil does not have any residual activity for weed control from application to the soil. Propanil activity is temperature-dependent; poor weed control may occur when temperatures are cool and rice injury can occur when temperatures are hot. Many different propanil formulations (i.e., dry

Table 7-3. Weed response ratings for rice herbicides.

HERBICIDES	HERBICIDE FAMILY	GRASSES								BROADLEAF WEEDS																SEDGES			
		Barnyardgrass[1,2]	Broadleaf Signalgrass	Crabgrass	Fall Panicum	Red Rice	Rice Cutgrass	Sprangletop (loosehead) (bearded sprangletop)	Sprangletop (tighthead) (Amazon)	Ammania (red stem)	Dayflower	Ducksalad	Eclipta	False Pimpernel	Gooseweed	Groundcherry	Hemp Sesbania (coffeebean)	Indian Jointvetch	Northern Jointvetch (curly indigo)	Palmleaf Morningglory	Pigweed, Palmer	Pitted Morningglory	Smartweed	Texasweed	Water Hyssop	Flatsedges	Spikerush	Umbrella Sedge	Yellow Nutsedge
Preemergence																													
League	2	0	0	0	0	0	0	0	0	7	-	5	-	-	-	-	9	8	8	2	0	2	7	8	-	8	-	0	8
Prowl delayed pre	3	8	6	8	7	0	0	6	6	0	0	4	0	0	0	-	0	0	0	0	6	0	0	0	0	0	0	0	0
Facet pre/delayed pre	4	9	9	9	9	0	0	0	0	3	5	3	8	3	3	8	6	7	7	7	4	7	0	0	6	5	-	0	0
Facet + Prowl delayed pre	4,3	9	9	9	9	0	0	7	7	3	5	3	8	3	3	-	7	7	7	8	6	8	0	0	6	5	-	0	0
Facet + Bolero delayed pre	4,8	9	9	9	9	0	0	8	8	6	7	7	9	7	5	-	8	8	8	8	5	8	5	-	6	8	7	4	0
Command + quinclorac, Obey	4,13	10	10	10	10	0	0	9	9	3	6	3	8	3	4	8	7	8	8	8	4	8	6	0	6	5	7	-	0
Bolero delayed pre	8	7	5	7	7	0	0	7	7	7	8	7	8	8	6	-	5	5	5	5	-	5	5	-	7	7	7	4	4
Bolero – Water seeded	8	8	7	7	-	8*	0	8	8	3	6	6	-	5	6	-	-	-	-	-	-	-	-	-	5	7	5	3	3
Command pre/delayed pre	13	9	9	9	9	0	0	9	9	0	3	3	3	-	0	-	2	3	3	4	0	3	2	0	0	0	0	0	0
Early Postemergence																													
Clincher	1	8	9	5	9	0	2	9	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Provisia fb Provisia	1	10	10	10	10	10	10	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ricestar HT	1	9	9	8	7	0	2	9	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grasp	2	8	0	0	0	0	6	0	0	7	8	9	8	-	-	8	8	8	8	4	0	5	7	7	8	9	8	0	6
Londax early post flood	2	0	0	0	0	0	0	0	0	9	7	9	8	9	9	0	6	6	6	5	0	5	6	0	9	8	8	0	6
Newpath fb Newpath/Beyond	2	9	9	9	9	9.5	9	8	7	8	5	7	0	0	5	9	0	0	0	5	0	7	9	5	0	9	9	0	8
Permit	2	0	0	0	0	0	0	0	0	5	8	3	5	-	4	6	9	3	6	0	0	4	4	5	-	8	-	0	9
Permit Plus	2	0	0	0	0	0	0	0	0	8	9	7	7	-	4	8	9	5	7	3	0	5	8	5	-	8	-	0	9
Gambit	2	0	0	0	0	0	-	0	0	9	9	8	8	-	4	8	9	9	7	3	0	6	8	7	-	8	-	0	9
Regiment	2	8	0	0	0	0	7	3	2	6	9	9	7	-	0	-	8	7	7	4	0	5	10	7	6	8	-	3	5
Strada	2	0	0	0	0	0	0	0	0	8	7	6	7	-	-	4	9	8	9	3	0	4	5	6	-	9	-	0	7
Facet early post	4	8	9	7	6	0	2	0	0	3	3	3	9	3	3	8	8	8	8	8	4	8	0	0	3	5	-	0	0
Loyant	4	7	8	0	-	0	-	6	6	10	10	10	10	10	9	-	10	10	10	5	9	8	6	-	8	10	-	10	7
Grandstand + Permit	4,2	0	0	0	0	0	0	0	0	8	8	4	5	-	-	4	8	9	9	9	4	9	7	9	-	9	-	3	9
Facet + propanil early post	4,7	9	9	7	9	0	2	4	5	6	5	6	9	7	5	8	9	9	9	8	8	8	6	6	8	9	9	3	5
Grandstand + propanil early	4,7	9	9	7	9	0	0	4	5	9	5	8	9	8	8	4	9	9	9	9	9	9	7	8	8	9	9	3	5
Basagran early	6	0	0	0	0	0	0	0	0	8	9	6	8	7	7	0	3	3	3	8	0	3	7	0	8	8	8	7	6
Basagran + propanil early	6,7	9	9	7	9	0	2	4	5	9	9	7	9	8	7	4	9	9	9	8	7	5	8	6	9	9	9	8	7
Propanil early (weeds less than 2")	7	9	9	7	9	0	1	4	5	6	5	7	8	7	5	-	9	9	9	4	7	4	6	6	8	9	9	5	4
Propanil fb propanil	7	9	9	7	9	0	2	7	8	6	6	7	9	7	5	-	9	9	9	5	9	5	8	6	8	9	9	6	6
Propanil + Londax or Duet prior to flood	7,2	9	9	7	9	0	2	4	5	9	8	7	9	8	9	0	9	9	9	9	7	9	8	5	8	9	9	6	8
Propanil + Permit	7,2	9	9	7	9	0	1	4	5	6	9	7	8	7	5	6	10	9	9	4	7	4	6	5	8	9	9	3	9
Propanil + Prowl early	7,3	9	9	7	9	0	1	9	9	7	5	7	9	7	6	-	9**	9**	9**	5	7	5	6	4	7	9	7	3	5
Propanil + Bolero early*	7,8	9	9	7	9	0	2	9	9	8	8	8	9	9	6	-	9**	9**	9**	5	0	5	6	4	9	9	9	8	5
Aim	14	0	0	0	0	0	0	0	0	6	7	5	7	-	-	8	9	6	6	10	6	10	9	3	7	0	0	3	0
Sharpen	14	0	0	0	0	0	0	0	0	8	7	5	9	-	7	8	9	9	9	9	9	10	-	8	8	8	-	6	6
Ultra Blazer + propanil early	14,7	8	8	7	8	0	1	4	5	6	5	7	8	7	5	8	9	6	9	8	9	8	7	3	8	8	8	2	5
Midseason																													
2,4-D	4	0	0	0	0	0	0	0	0	9	9	9	9	9	6	5	9	5	5	9	8	9	6	0	9	8	8	3	5
2,4-D + propanil for levees	4,7	6	6	2	6	0	0	6	6	9	9	8	9	9	8	5	9	8	8	8	9	9	7	0	9	8	8	3	6
Grandstand + propanil	4,7	4	4	4	4	0	0	0	0	9	-	6	6	8	7	3	9	8	9	9	7	9	5	0	8	5	8	5	3
Propanil	7	4	4	4	4	0	0	0	0	4	0	3	4	4	0	4	8	5	5	3	6	0	3	0	8	5	7	5	3
Propanil + Ultra Blazer	7,14	5	5	5	5	0	0	0	0	5	2	4	5	5	2	5	9	6	6	7	7	8	7	0	8	6	7	5	4
Ultra Blazer	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	9	0	0	3	6	3	6	0	0	0	0	0	0

[1] Some biotypes of barnyardgrass in Arkansas are resistant to Command, propanil, Facet or both (Facet + propanil), and Newpath, Grasp, and Regiment.
[2] Loyant will control propanil-, Facet- or Newpath-resistant barnyardgrass when applied 3-4 days pre-flood.

*Water seed pin-point flood culture. **Postemergence control only.
Rating Scale – 0 = No Control 10 = 100% Control.

flowable, SC and EC) are available and require different spray techniques. The addition of spray adjuvants to dry flowable and SC formulations is required by the labels. Spray adjuvants are not required for EC formulations. A maximum of 6 pounds a.i. per acre propanil (6 quarts per acre of 4 a.i./gal formulations) can be applied during a single growing season. A maximum of 6 pounds a.i. per acre can be applied in a single application. Below are several use precautions/tips for propanil use in weed control programs.

- Apply to grass in 1- to 3-leaf stage (Table 7-4).
- Best activity when daytime maximum temperatures are above 75°F.
- Weeds must be actively growing. Flush before spraying if weeds are moisture-stressed.
- Apply in 10 gallons water per acre to obtain good coverage.
- No surfactants, oils or additives are recommended unless using dry flowable or flowable formulations.
- Application when temperatures are > 95°F may burn rice, and propanil should not be applied at such high temperatures.
- Carbamate (Sevin, etc.) and organophosphate (methyl parathion, etc.) insecticides should not be applied within 14 days before or after propanil.

Table 7-4. Weed sizes for optimum control with propanil†.

Weed	Weed Height	Number of Leaves
	inches	#
Fall panicum	1-3	1-3
Broadleaf signalgrass	1-3	1-3
Sprangletop	1-2	1-2
Morningglory	3	2-3
Ducksalad	1	2
Redstem	1	2-4
Smartweed	2	2-4
Volunteer milo	5	4-6
Northern jointvetch	12	--
Hemp sesbania	36	--
Flatsedge	1-2	3

† Use 4 lbs per acre rate if 4-leaf barnyardgrass is present or on larger stages of weeds listed above.

- Prevent drift of the above-listed insecticides from adjacent wheat fields onto rice during the propanil-use season.
- Avoid contaminating mixing and spray equipment with insecticides when using propanil.
- Cotton is extremely sensitive to propanil drift, and heavy drift rates prior to cotton emergence can cause injury.
- Soybeans are sensitive to propanil drift.
- Avoid drift to gardens.

Propanil-resistant barnyardgrass has been found throughout most of Arkansas. Propanil-resistant barnyardgrass occurs most frequently in fields where rice has been grown continuously or in a 1:1 rice-soybean rotation. Resistance occurs less frequently in fields where rice is followed by two years of soybean in rotation. Herbicides that control propanil-resistant barnyardgrass include Bolero, Clincher, Command, Facet, Prowl, Ricestar HT and tank mixtures of these herbicides. Strategies for preventing and managing propanil-resistant barnyardgrass include:

- Use a one-year rice followed with a two-year alternate crop rotation where possible.
- Use residual herbicides such as Bolero, Command, Facet or Prowl with propanil.
- Use Command and/or Facet preemergence or delayed preemergence.
- Do not use the same herbicide strategy more than two consecutive times on a field that is in rice.

Clincher and Ricestar HT

Clincher and Ricestar HT are both effective for control of barnyardgrass and other grass weeds of rice. They will control both Facet and propanil-resistant barnyardgrass. As with other graminicides, tank mixtures with 2,4-D and other broadleaf herbicides may result in antagonism. Performance of these herbicides is severely reduced under dry conditions. Clincher provides good control of barnyardgrass up to 10 days postflood. At least two-thirds of target weeds should be above flood water. Excellent spray coverage is needed with both Ricestar HT and Clincher. These products do not injure soybeans.

Residual Herbicides

Herbicides that provide residual weed control from soil application are Bolero, Command, Facet, League, Newpath and Prowl. A preemergence application of Command has become the standard starting point for a rice weed control program. However, these herbicides may be tank mixed with propanil and other products for contact and residual grass control or used alone prior to weed emergence in most dry-seeded rice weed control programs. In situations where postemergence applications may be difficult, combinations of Command or Prowl plus Facet or Bolero are often used for extended residual weed control. Because of the development of resistant biotypes of barnyardgrass and difficulties with post emerge applications, it is strongly recommended that preemergence herbicides be flushed in if it does not rain.

Bolero 8E

Environmental and cultural practices affect the length of residual activity of Bolero. Bolero can be applied delayed preemergence or postemergence with propanil. Bolero may injure rice if applied before germination water is imbibed. To prevent injury and maximize Bolero activity, apply to a soil surface that has been sealed by a rain or flushing. Residual activity is decreased if the soil becomes dry and cracks. Bolero (3 to 4 pints per acre) applied as a delayed preemergence treatment provides excellent control of sprangletop, barnyardgrass and several aquatic weeds. Delayed preemergence applications should be made 1 to 5 days before rice emergence or about 5 to 9 days after planting, provided that adequate moisture is present for rice seed to have imbibed water for germination. Drain any surface water before Bolero application. A rainfall or flush is required for activation if the soil begins to crack or if grass begins to germinate. Bolero provides poor control of broadleaf signalgrass. A maximum of 4 pounds a.i. per acre (4 pints per acre) can be applied during a single growing season. Most Bolero is applied either tank mixed with Prowl or Facet as a delayed preemergence treatment or with propanil as an early postemergence treatment. Bolero has been used extensively for aquatic weed control in water-seeded rice. Refer to Table 7-3 for more detail on specific weed control ratings with Bolero.

Command 3ME

Applied preemergence, Command provides excellent control of barnyardgrass, sprangletop and broadleaf signalgrass. The Command rate will influence the length of residual. Research has shown excellent residual grass control from 0.3 pound a.i. per acre on silt loam soils. A followup herbicide treatment is generally required before flooding to “clean up” annual sedges and broadleaf weeds. Broadleaf signalgrass will usually be the first grass to “break” following application.

Command can be applied to dry-seeded rice from 14 days before seeding to 7 days after seeding. If applied before seeding, do not incorporate. Application rates vary with soil texture. Silt and sandy loam soils require 0.28 to 0.38 pounds of active ingredient per acre (12 to 16 ounces per acre), and 0.47 to 0.56 pounds of active ingredient per acre (20 to 24 ounces per acre) is recommended for clay soils. Labeled application rates range from 16 to 24 ounces per acre. Some bleaching can be expected following Command application, especially following a flush or a soaking rain in cool temperatures. Bleaching gradually diminishes as the soil dries but may return with flushing or rainfall. Bleaching is generally not a problem, causes no yield loss or reduced seedling vigor and is greater on the sandy and silt loam soil textures.

If rice is seeded into a stale seedbed, care should be taken to insure the drill gaps close and cover the seed. (This is a good idea regardless of whether Command is used or not. Recent data suggests that open furrows with Command result in no worse injury that open furrows without Command – open furrows typically result in reduced stands compared to closed furrows). Shallow seeding, herbicide overlaps and other factors that result in poor application accuracy or slow-growing rice may increase early-season bleaching.

Levees pulled after Command application may require additional weed control. Refer to Table 7-3 for specific weed control ratings.

Quinclorac (Facet 75DF, Facet L, Quinstar)

Quinclorac is primarily a grass herbicide that also controls several important broadleaf weeds. Quinclorac can be applied preemergence, delayed preemergence or early postemergence. Quinclorac may also be applied to the soil surface prior to planting in stale or no-till seedbeds. Quinclorac enters weeds mainly through root uptake; therefore, adequate moisture is important for maximum activity. Rice must be at least in the 2-leaf stage for quinclorac use in water-seeded rice and the flood water must be drained before application.

The labeled application rates for quinclorac are dependent on soil texture. Coarse (sandy loam) soils require 0.33 pounds per acre, silt loams require 0.5 pounds per acre and clay and clay loams require 0.67 pounds per acre for preemergence and delayed preemergence weed control. Quinclorac should not be used on sandy soils with poor water-holding capacity because it may leach and reduce weed control. Delayed preemergence or early postemergence applications of quinclorac should be made to a moist soil or when frequent rains or flushing keeps the soil moist for improved weed control to be expected.

For foliar or postemergence grass control, the recommended application rates are from 0.17 to 0.67 pound per acre depending on soil texture and the length of desired residual control. Crop oil or an EC propanil formulation should be tank mixed with quinclorac for postemergence weed control. Crop oil concentrate is required for quinclorac applied alone or tank mixed with flowable or dry flowable propanil formulations. If an EC formulation of propanil is used, spray adjuvants are not needed. A maximum of 0.75 pounds per acre can be applied during a single growing season.

Rice tolerance to quinclorac has been excellent regardless of application method. However, if rice seeds are exposed to direct spray or young plants are under stress, injury may occur. Quinclorac provides excellent residual control of barnyardgrass, broadleaf signalgrass, morningglory, hemp sesbania and northern jointvetch. Quinclorac has little or no activity on sprangletop, smartweed or nutsedge. If fields have a history of these weeds, a tank mix with another herbicide or a preflood application of another herbicide may be necessary. Although common purslane and carpetweed are not controlled by quinclorac, these weeds should be controlled by the flood. If weeds emerge after application, rainfall or flushing may be required for activation and reactivation. Tomatoes and cotton are extremely sensitive to quinclorac. Follow all Arkansas State Plant Board application guidelines to reduce drift and prevent injury to nontarget plants.

League

League is a Group 2 systemic herbicide that provides both preemergence (residual) and postemergence control. League should be applied preemergence at 6.4 fl oz/A, which should provide effective control of rice flatsedge (annual sedge), yellow nutsedge, hemp sesbania (coffeebean), northern jointvetch and Texasweed. Seed directly exposed to League may be injured; hence, soil should be sealed prior to application. Postemergence applications of League are recommended at 3.2 fl oz/A plus NIS at 0.25% v/v, which allows for sequential applications if needed. Postemergence applications will provide control of a similar spectrum as preemergence applications; however, residual control will be reduced due to the lower use rate of the postemergence application. It should be noted that ALS-resistant populations of rice flatsedge and yellow nutsedge exist, and League will provide no control of these resistant populations. League can be tank-mixed with Command when applied preemergence for control of a broad assortment of grasses, broadleaves, and sedges. Postemergence tank-mix options may include Newpath in Clearfield rice or Facet or propanil in conventional rice.

Prowl H_2O

Prowl can applied (delayed preemergence) for residual grass control or be tank mixed with Facet, Bolero or propanil in early postemergence applications. Prowl should only be used on dry-seeded rice. When applied as a delayed preemerge, the soil should be sealed by a rain or flush and any surface water should be drained before application to prevent crop injury. Rice seed should have imbibed germination water before application. Prowl controls both barnyardgrass and sprangletop but is weak on broadleaf signalgrass. Refer to Table 7-3 for specific weed control ratings.

Broadleaf and Aquatic Weed Control

Broadleaf weeds reduce rice yield by direct competition and also reduce grade if they produce dark-colored seeds. The broadleaf weeds – dayflower, hemp sesbania, northern jointvetch, smartweed and morningglory species – are dark-seeded weeds common in much of Arkansas. These broadleaf weeds will not germinate once a permanent flood is established. However, they are problems if they emerge prior to flooding or if they emerge after flooding on levees or areas in the paddy that are allowed to dry. Hemp sesbania, northern jointvetch, palmleaf morningglory, dayflower and smartweed thrive in flooded soils if they are allowed to emerge prior to flooding. Other morningglory species like entireleaf or pitted morningglory do not usually survive prolonged flooding. All morningglory species can be problems on levees. Other weeds that can be found on levees include cutleaf groundcherry, sicklepod, cocklebur, velvetleaf and pigweed. Eclipta is another broadleaf weed that survives flooding, may interfere with harvest and increases moisture of harvested grain.

Most broadleaf weeds can be controlled before or after flooding without yield or quality loss. Because broadleaf weeds usually emerge after barnyardgrass, herbicides that control broadleaf weeds are usually applied shortly before or after flooding. Most broadleaf weeds common to Arkansas rice cultures are annual weeds germinating from seed; therefore, they are usually easier and more economical to control when they are small. There are numerous preflood control options that can be used alone or in combination to provide good broadleaf weed control. General use guidelines for several herbicides that are specific for broadleaf weed control are reviewed below. Refer to Table 7-3 for specific weed control ratings for each herbicide.

Aim

Aim is a contact herbicide with no residual that can be applied alone for effective control of cocklebur, jointvetch, hemp sesbania, smartweed and morningglories. It is a relatively inexpensive herbicide that performs well under good conditions and on small weeds. It can be tank mixed with Facet or propanil on larger weeds or to improve its spectrum of weeds controlled. Aim can also be applied as a harvest aid for morningglories up to 3 days prior to harvest.

Basagran, Ultra Blazer and Storm

Basagran, Ultra Blazer and Storm can be applied alone or tank mixed with propanil to increase their spectrum of control. Storm is a package mix of Basagran and Ultra Blazer labeled for rice. Storm applied at 1.5 pints per acre is equal to 1 pint of Ultra Blazer plus 1 pint of Basagran.

Basagran tank mixed with propanil will increase activity on smartweed, cocklebur, redstem, dayflower, spikerush, yellow nutsedge and flatsedge. For most effective control, Basagran should be applied when broadleaf weeds are small. Basagran does not provide residual control.

Ultra Blazer can be tank mixed with propanil and applied preflood to control small morningglories. Ultra Blazer applied alone may also be used to control large hemp sesbania postflood. Apply Ultra Blazer when hemp sesbania is 1 to 5 feet and morningglory runners are less than 1 foot long. Propanil plus Ultra Blazer is a good levee treatment for groundcherry and is a good alternative for 2,4-D levee sprays if cotton or other sensitive crops are nearby. Ultra Blazer may cause foliar burn on rice, but symptoms will be quickly outgrown. Label restrictions prohibit applying more than 1 pint Ultra Blazer per acre per season. The addition of Ultra Blazer may reduce propanil activity on grasses. Ultra Blazer must be applied 50 days before harvest or no later than the early boot stage. When applied alone, Ultra Blazer requires the addition of a surfactant.

Grandstand-R 3SL

Grandstand is a hormone-type herbicide that can be applied preflood or postflood. It is commonly tank mixed with propanil to increase the spectrum of control. Grandstand plus propanil provides control of northern jointvetch, hemp sesbania, morningglory and several aquatic weeds.

Grandstand may be applied to dry- or water-seeded rice starting at the 2- to 3-leaf stage. The flood must be delayed for 72 hours to prevent injury from Grandstand applications made prior to flooding. For postflood application, weeds should be exposed before application. If the flood is lowered for this purpose, the crown of rice plants should not be exposed above the water level. Flood level should not be raised for 48 hours after application. To avoid rice injury and possible yield loss, Grandstand should not be applied after ½ inch internode elongation. If more than one application is made to rice during a single season, applications must be at least 20 days apart. A maximum of 2 pints per acre Grandstand 3SL can be applied per season but only 1 pint per acre for each application. A surfactant or crop oil concentrate will enhance performance if Grandstand is applied alone or with dry-flowable formulations of propanil.

Coverage of weed foliage is important for optimum control. The Grandstand label prohibits tank mixes with liquid nitrogen and zinc fertilizers. Spray to drift to sensitive crops, especially cotton or blooming soybeans, should be avoided. Cotton is less sensitive to Grandstand than to 2,4-D, but drift rates may cause yield reductions. A preplant burndown application may be made at least 21 days before rice is dry seeded or 14 days before water seeded.

Londax 60DF

Londax is a herbicide that is primarily used for aquatic weed and yellow nutsedge control. Londax plus propanil applied immediately (1 to 7 days) before flooding provides control of annual sedges and yellow nutsedge. Londax is highly water soluble and will move with irrigation water. For best results, permanent flood should be maintained and kept as static as possible for 7 days after application. A tank mixture of Londax with propanil also increases control of several broadleaf weeds (i.e., smartweed, redstem and eclipta) compared to propanil alone. Some aquatic weeds (i.e., redstem and arrowhead) have developed resistance to Londax and must be controlled by other herbicides. Weed resistance is most likely to develop in fields where Londax is used continuously, such as in water-seeded fields. Failure to control aquatic weeds in water-seeded fields may suggest the beginning of weed resistance to this herbicide.

For postflood applications, Londax should be applied within 5 days after flooding when target weeds are small. For water-seeded rice, Londax should be applied as soon as possible after rice has pegged and the flood is stabilized. Londax is weak on emerged ducksalad and roundleaf mud plantain but provides excellent control before they emerge. In water-seeded rice, excessive pumping (water flow) after application may result in poor control in the upper paddies. Londax is a slow-acting herbicide and may require several days before weeds begin to die. Most consistent results are obtained on aquatics before or just at emergence.

When applied alone or tank mixed with a dry-flowable propanil formulation, 0.25 percent nonionic surfactant or 1 percent (1 gallon per 100 gallons) crop oil concentrate should be added for improved control. Londax has a 60-day preharvest interval, and a maximum of 1.67 ounces per acre can be applied during a single growing season.

Loyant

Loyant is a group 4 hormone-type herbicide that can be applied to rice from early-postemergence up until 60 days prior to harvest. The use rate for Loyant is 1 pint of product per acre, with no more than two applications per year. If sequential applications of Loyant are made, allow 14 days between applications. A methylated seed oil is recommended with all Loyant applications. Loyant works best when applied pre-flood, with the permanent flood established as soon as possible and no more than 7 days after application. Loyant has some activity on barnyardgrass and broadleaf signalgrass, but results may depend on amount of moisture available, size of the grass, and timing of the flood. Excellent activity has been observed on annual sedges and many broadleaf and aquatic weeds. It is weak on crabgrass and sprangletop sp. Loyant is an excellent option for the control of Palmer amaranth early-postemergence, on levees and in row-watered rice. Care should be taken to not drift Loyant onto adjacent soybean fields as severe damage will occur (see label for restrictions). Certain cultivars can display increased sensitivity to Loyant, particularly hybrids and some long-grain varieties. Medium-grain variety crop response has been variable, while Clearfield varieties have displayed minimal crop response.

Permit or Permit Plus

Permit is generally the best herbicide choice for the control of yellow nutsedge in rice. Unlike Londax, the flood does not need to be applied following application for effective yellow nutsedge control. Permit can also be applied with a burndown herbicide like Roundup before rice is planted in situations where heavy yellow nutsedge infestation occurs before seeding. Permit is labeled for application from prior to rice emergence until after the flood is established. Labeled application rates range from 0.67 to 1.33 ounces per acre. If applied alone or tank mixed with a dry flowable propanil formulation, addition of 0.25 to 0.5 percent nonionic surfactant or 1 percent (1 gallon per 100 gallons) crop oil concentrate is recommended. Permit can be weak on certain broadleaf and aquatic weeds. However, Permit alone or tank mixed with propanil provides excellent control of hemp sesbania and dayflower. Permit tank mixed with propanil offers broader spectrum weed control. Soybeans are very sensitive to Permit, and caution should be taken to avoid drift to soybeans. Permit Plus will control weeds like smartweed, sesbania, jointvetch and other weeds more effectively than Permit.

Sharpen

Sharpen is a Group 14 contact herbicide that has slight residual activity on some small-seeded broadleaf weeds such as Palmer amaranth. When applied alone, it provides effective control of Palmer amaranth, morningglories, hemp sesbania (coffeebean), northern jointvetch, eclipta, groundcherry and ammania. Sharpen can be applied burndown through preemergence at 1.0 to 2.0 fl oz/A with MSO at 1% v/v. Once rice reaches the 2-leaf stage, Sharpen can be applied at 1.0 fl oz/A with COC at 1% v/v up to internode elongation. Leaf necrosis (burn) may occur soon after application but will not likely persist more than 10 to 14 days. Do not add MSO to Sharpen when applying to emerged rice or crop death may result. Sharpen can be tank-mixed with Facet or propanil to broaden spectrum of control or aid in control of larger weeds. Tank-mixing Sharpen with Ricestar HT or Clincher may reduce the level of grass control obtained with the graminicide.

Strada

Strada is a sulfonylurea herbicide similar to Permit in weed spectrum and activity. One difference is that Permit has better activity on yellow nutsedge. Strada provides good control of hemp sesbania, northern jointvetch and flatsedge. Strada fits into a weed control program with Command, propanil or Newpath. The use rate for Strada herbicide is 1.7 to 2.1 ounces per acre. To improve Strada WG performance, an addition of organo-siliconic or nonionic surfactant at the rate of 0.125 and 0.25 percent v/v (0.5 to 1 quart per 100 gallons of spray solution volume), respectively, is recommended. Do not apply Strada after ½ inch internode elongation.

Regiment

Regiment is a unique herbicide in that it controls a limited spectrum of both grass and broadleaf weeds. These weeds include barnyardgrass, johnsongrass, smartweed, ducksalad, dayflower, flatsedge and hemp sesbania. The use rate for Regiment ranges from 0.4 to 0.63 ounces per acre. Regiment should be applied with both a silicon-based adjuvant and liquid ammonium sulfate. University of Arkansas data has shown that including the fertilizer adjuvant to Regiment will improve activity and consistency on barnyardgrass. Regiment should be applied between 4-leaf rice and joint movement. Do not apply past panicle initiation (beginning internode elongation) or unacceptable injury may occur. Regiment can cause root injury, especially if higher than labeled rates are applied. In University trials, most injury from Regiment has not affected yields.

Grasp

Grasp can be applied early postemergence until within 60 days of harvest. Use rates of Grasp range from 2 to 2.3 ounces per acre. One quart per acre of crop oil concentrate or methylated seed oil should be added to all Grasp applications. Grasp has excellent activity on ducksalad and rice flatsedge. It also controls barnyardgrass, jointvetch and hemp sesbania. If applied at higher than labeled rates, root injury and some stunting may be observed. Flooding should be delayed for 3 days following applications of Grasp. Water-seeded rice should be well rooted prior to application.

2,4-D

Many different formulations of 2,4-D are available for application to rice. The herbicide provides economical control of many broadleaf and aquatic weeds in rice. Northern jointvetch is not effectively controlled with 2,4-D. The recommended application window for 2,4-D use on rice is very narrow. Use the DD50 prediction as a guide for application, or apply when the first elongating internode begins movement. Do not apply when internode length exceeds ½ inch. Application after ½ inch internode elongation may result in severe crop injury and yield loss. To hasten recovery of the rice plant, apply 20 to 30 pounds nitrogen per acre within 5 days after phenoxy herbicide treatment. If nitrogen is applied first, a phenoxy herbicide can be safely applied within 5 days after nitrogen application, provided the first elongating internode is no longer than ½ inch. State Plant Board regulations must be followed concerning applications near sensitive crops. These restrictions currently impose a ban on the use of 2,4-D by both air and ground after April 15. Restrictions on 2,4-D change from time to time, so please consult the Arkansas State Plant Board web site for the most current information.

Aquatic Weed Control

Aquatic weeds germinate and thrive in saturated or flooded soils. Ducksalad, purple ammannia (redstem), gooseweed, arrowhead, false pimpernel and roundleaf mud plantain are found in most Arkansas rice fields. These aquatic weeds compete with rice and interfere with harvest. Aquatic weeds are generally more prevalent and yield reductions are greater in thin stands of rice and in water-seeded fields. Establishing an adequate stand of rice will reduce the potential number of aquatic weeds, as well as the potential rice yield reductions from the competition of aquatic weeds. Herbicides that control aquatic weeds include Londax, Bolero and 2,4-D. Bolero is used preflood, Londax can be used early postflood and 2,4-D can only be used from panicle initiation to panicle differentiation (½ inch internode elongation).

Harvest Aids – Sodium Chlorate

Sodium chlorate is commonly used to desiccate green foliage and weeds present in rice fields to increase harvest efficiency. The general guidelines are to apply sodium chlorate at 3 to 6 pounds a.i. per acre when rice grain is near 25 percent moisture and harvest within 4 to 7 days after application. Although sodium chlorate is typically used to desiccate the vegetation, grain moisture is also reduced. Research suggests that when used properly, sodium chlorate does not reduce head rice yield (Table 7-5). However, application of sodium chlorate at 6 pounds a.i. per acre significantly reduced grain moisture by 2 to 5 percent within 4 days after application. Head rice yields may decline if grain moisture drops below 15 percent before grain is harvested. Thus, sodium chlorate should be applied to rice that is between 18 and 25 percent moisture with timely harvest following application. Use of sodium chlorate on seed production fields is sometimes needed. Research has shown that sodium chlorate does not influence germination of the resulting seed (Table 7-6).

Desiccation of rice foliage is noticeable within 36 hours after application, especially when temperatures are high. Sodium chlorate may also reduce head rice and grain yield if applied too early, before grain fill is complete. Growers should exercise caution when considering sodium chlorate application to fields with uneven maturity to avoid yield and quality losses.

Table 7-5. Influence of sodium chlorate on rice grain yield and harvest moisture during 2000†.

Sodium Chlorate Rate	Grain Yield	Harvest Moisture‡	Head Rice	Milled Rice
lbs/A	bu/a	percent		
0	173	21.1	57.5	70.3
6	174	17.8	56.1	70.0
$LSD_{(0.05)}$	NS	11.3	NS	NS

† Study conducted at the Rice Research and Extension Center. Data is the mean for Wells and Cocodrie and across application times.

‡ Grain moisture averaged 23% on the day of sodium chlorate application.

Source: Wilson et al., 2001. p. 437-445. B.R. *Wells Rice Research Studies 2000*. Ark. Agr. Exp. Sta. Res. Ser. 485.

Table 7-6. Influence of a preharvest application of sodium chlorate on germination of resulting seed†.

Sodium Chlorate Rate	Seed Germination			
	Bengal	Cocodrie	Drew	Wells
lbs/A	percent			
0	93.5	92.0	93.7	92.3
6	95.7	90.5	96.5	94.8
$LSD_{(0.05)}$	NS	NS	NS	NS

† Study conducted at the Rice Research and Extension Center during 1999.

Source: Wilson et al., 2001. p. 437-445. *B.R. Wells Rice Research Studies 2000.* Ark. Agr. Exp. Sta. Res. Ser. 485.

Chapter

8

Chemical Applications

Jarrod Hardke, Gus Lorenz, Bob Scott and Richard Norman

Rice production efficiency and profitability are enhanced through the use of agricultural chemicals, including pesticides and fertilizers. Factors such as chemical selection and the timing and accuracy of applications can enhance the value and increase the economic return of these inputs. A variety of application techniques are used to apply chemicals to rice. Early-season chemical applications, prior to flooding of rice fields, are generally split between ground-based and aerial platforms. However, once fields are flooded, the primary application tool is the agricultural aircraft.

Global positioning systems (GPS) or satellites have been in widespread use for a number of years to provide guidance for chemical applicators. GPS is a very accurate method to follow a prescribed path in the field for each pass. Thus, flaggers are no longer needed, and the GPS provides a logistical value to applicators. Chemical applications can be made to fields at any time without having to coordinate the exact application time. GPS also has the ability to track the application operation, which provides an excellent record of the many application variables.

Soil Applications of Pesticides

Ground-Based Applications

Many growers use ground equipment to apply pesticides before planting and flooding. The focus of most chemical applications centers on application dosage accuracy, swath uniformity and drift minimization. Almost all nozzle manufacturers offer a table-based guide to assist applicators with the correct nozzle selection for each type of chemical used. These should be studied carefully to determine which nozzle type and setup will provide the best performance. Many nozzle manufacturers offer excellent web sites with selection and calibration information. Examples include www.teejet.com, www.greenleaftech.com and www.sprayparts.com.

Photo 8-1. **Ground-based burndown herbicide application.**

Many manufacturers are using an air induction-type nozzle to help control droplet size – particularly to reduce the number of fine or small droplets that are produced. Proper selection of air induction-type nozzles helps keep the droplet size within the desired range. Most ground-based pesticide applications should perform well with droplet spectrums that provide a VMD (volumetric mean diameter) in the range of 300 to 600 microns (µm). One micrometer, or micron, is 1/25,000 of an inch – the diameter of a human hair is approximately 100 µm. ASABE (American Society of Agricultural and Biological Engineers) has developed standards, ASABE S572, to describe names for droplet spectrums such as fine, medium and coarse. These names fully define the spectrum for fine, average and large droplets in the spectrum. Most rice applications utilize the medium droplet spectrum. Utilization of these names is very common as restrictions or guidelines on chemical labels.

Larger droplets (500 to 1,000 µm) are typically used for ground contact applications because coverage may not be as critical. Applications on leaf surfaces should be targeted for droplet spectrums in the 150 to 400 µm range. Nozzles on large floater trucks that are used for liquid fertilizer applications typically make a droplet size too large for adequate performance when applying to plant surfaces. Fertilizer-type flood nozzles may even produce droplets that are too large for soil-applied pesticides and should be used with caution. Carefully study the data available and select the best suited nozzles. Manufacturers typically offer bar graphs that help with selection based on chemical mode of action.

Aerial Applications

When early-season rainfall prevents ground-based burndown applications, many pesticide applications are done by agricultural aircraft. Development of new nozzle technology and performance evaluation techniques has allowed pilots to customize the aircraft to increase application efficiencies, making aircraft an excellent spray platform.

Photo 8-2. Aerial application of postemergence herbicide.

Spray pattern uniformity, droplet size and application dosage should be carefully evaluated with all types of sprayers. New GPS feed rate controllers allow applicators to maintain application spray rates within ±1 percent of the target rate. This technology is becoming more common. Estimates are that at least 10 percent of the Arkansas aircraft fleet has rate controllers.

Table 8-1. Spray tip classification by droplet size.

Classification Category	Color Code	Droplet Size	Approximate VMD (µm)†	Coverage	Used for	Drift Potential
Extremely Fine	Purple	Small	<50	Excellent	Exceptions	High
Very Fine	Red	↓	51-150	Excellent	Exceptions	↓
Fine	Orange		151-230	Very Good	Good Cover	
Medium	Yellow		231-340	Good	Most Products	
Coarse	Blue		341-405	Moderate	Systemic Herbicides	
Very Coarse	Green		405-505	Poor	Soil Herbicides	
Extremely Coarse	White		506-665	Very Poor	Liquid Fertilizer	
Ultra Coarse	Black	Large	>665	Very Poor	Liquid Fertilizer	Low†

† Estimated from sample reference graph in ASABE/ANSI/ASAE Standard S572.1 2009. Spray Nozzle Classification by Droplet Spectra. American Society of Agricultural and Biological Engineers.

Postemergence Applications of Pesticides

Ground-Based Applications

Ground-based postemergence pesticide applications to flooded rice fields can be difficult. These applications work best when specialized equipment is used or on applications made to precision-leveled fields with straight levees or on zero-grade fields with no levees. Typical ground-based application equipment may have problems with traction in the flooded fields and can damage levees to the point that using the equipment is impractical.

Aerial Applications

Most postemergence pesticide applications, especially those applied to flooded fields, are made using agricultural aircraft. Some postemergence pesticides are applied in a granular form (i.e., Facet®). These materials are generally applied at rates of 15 to 30 pounds per acre. Agricultural aircraft spreaders are typically designed to make applications at rates of 100 pounds per acre or higher. Spreaders can be set to make these lower application rates, but attention to setup details is more critical. These materials can be distributed quite accurately when aircraft are properly adjusted.

Photo 8-3. Aircraft spreader

Foliar insecticide applications are commonly needed for control of rice insect pests. When insecticide applications are needed to control insects there are several considerations that should be made:

1. **Time of day.** Many insects are more active early in the morning or late in the evening, and applications should be made to coincide with when insects are up on the plant where they can be reached with the application.

2. **Environmental conditions.** Mobile insects, such as rice stink bug adults, may move out of the field on hot, sunny days, and applications made in the middle of the day may occur when insect populations have temporarily moved out of the field. When temperatures are high, increasing spray volume (GPA) and the use of an adjuvant may improve deposition and coverage of insecticides.

3. **Insecticide selection.** Some insecticides have longer residual than others. Some are more appropriate for the pests that you are trying to control. Select the correct insecticide based on pest pressure. Refer to Chapter 12, Insect Management in Rice, or MP144, *Insecticide Recommendations for Arkansas* (https://www.uaex.edu/publications/mp-144.aspx) for additional information on insecticide ratings and selection.

Pesticide Drift

EPA, http://www.epa.gov/PR_Notices/prdraft-spraydrift801.htm, defines pesticide drift as:

"Spray or dust drift is the physical movement of pesticide droplets or particles through the air at the time of pesticide application or soon thereafter from the target site to any non- or off-target site. Spray drift shall not include movement of pesticides to non- or off-target sites caused by erosion, migration, volatility, or windblown soil particles that occurs after application or application of fumigants unless specifically addressed on the product label with respect to drift control requirements."

Buffer or no spray zones are also defined by:

"A no-spray zone is an area in which direct application of the pesticide is prohibited; this area is specified in distance between the closest point of direct pesticide application and the nearest boundary of a site to be protected, unless otherwise specified on a product label."

Pesticide drift refers to the movement of a pesticide away from the target application site. Pesticide drift occurs when pesticide applications are made in high winds or when conditions exist for temperature inversions. Under these conditions, rice herbicides can cause damage to susceptible crops. This damage can range from cosmetic to complete loss of the susceptible crop. The level of damage caused by pesticide drift depends on the sensitivity of the nontarget crop to the pesticide and upon the amount of the pesticide drifted. Table 8-2 lists several common rice herbicides and the relative sensitivity of nontarget crops. It can often be difficult to determine the exact economic loss caused by pesticide drift. Many factors including weather and overall growing conditions can influence the ability of nontarget plants to recover from drift. The information below is meant only to provide general guidelines.

Table 8-2. Relative sensitivity† of major Arkansas field crops to commonly used rice herbicides.

Herbicide (trade name)	Herbicide (common name)	Soybean	Corn	Cotton	Milo	Rice
Numerous	glyphosate	T*	T*/VS	T*/S	VS	VS
Newpath	imazethapyr	T	S	S	S	T*/VS
Facet	quinclorac	M	M	S	T	T
Prowl	pendimethalin	T	T	T	M	T
Command	clomazone	T	M	M	M	T
Numerous	propanil	S	S	S	S	T
Regiment	bispyribac	M*/VS	S	S	S	T
Permit	halosulfuron	T*/VS	T	S	T	T
Grasp	penoxsulam	M*/VS	S	S	S	T
Londax	bensulfuron methyl	M*/VS	S	S	S	T
Strada	orthosulfamuron	M*/VS	S	S	S	T
Ricestar	fenoxaprop	T	VS	T	VS	T
Clincher	cyhalofop	T	VS	T	VS	T
Blazer/Storm	acifluorfen	T	M/S	M	M/S	T
Numerous	2,4-D	S	T	VS	T	T
Grandstand	triclopyr	S	M	S	M	T
Aim	carfentrazone	M	M/S	M/S	M/S	

† T = Tolerant, M = Moderately Tolerant, S = Sensitive, VS = Very Sensitive.
T* = Some crops are available with herbicide tolerance to these herbicides.
M* = Some crops are available with moderate herbicide tolerance to these herbicides.

Flag the Technology

Flag the technology is a program designed to help prevent herbicide drift issues. Many herbicide-tolerant crops are now available that allow certain broad-spectrum herbicides to be applied without causing crop injury. While multiple herbicide tolerance technologies are available, only one such technology, Clearfield, exists for rice. The use of colored marker flags (Figure 8-1) is intended to prevent application errors and herbicide drift issues with nearby crops. In rice, fields planted with Clearfield technology should be marked with bright yellow flags while all others (with no herbicide tolerance) should be marked with red flags. Yellow flags marking soybean fields in and around rice indicate that those fields are STS soybeans. STS soybeans can tolerate rice herbicides such as Permit. Although injured less than conventional soybeans, STS soybeans may still be injured by drift from certain rice herbicides such as Regiment.

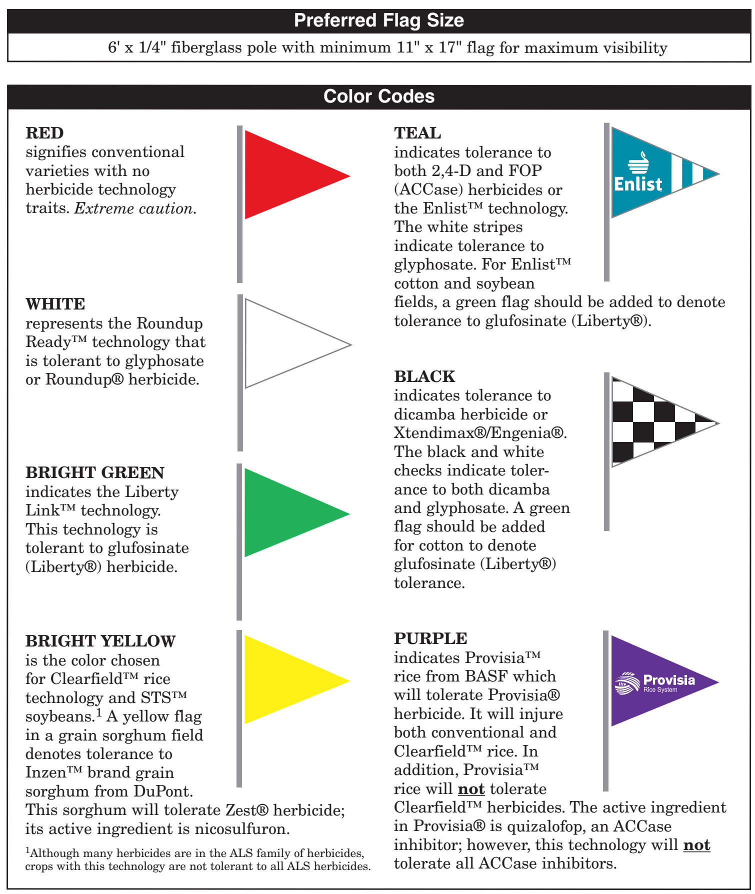


Figure 8-1. Key to Flag the Technology marker flag colors.

Fertilizers

Ground Applied

Spinner Units

Many applications are done prior to flooding using trucks and/or buggies with rotating spinner applicators. These units may do an excellent job of spreading, but they need to be adjusted carefully for the various application rates and material types used. There is no one setting that will provide a uniform distribution of all materials and application rates.

Photo 8-4. Spinner truck applying fertilizer.

Spinners should be carefully calibrated and the distribution pattern tested during the off-season to determine gate openings, spinner speeds, blade angle settings and feed point adjustments that will provide the best field uniformity. Optimum swath widths will also vary – so they should be noted as well during the calibration process.

Swath calibrations are typically done with a set of 11 to 25 pans that are about 6 inches tall and about 15 inches square. A fabric or grid is used in each pan to avoid "bounce out." These pans are spread out evenly and the unit operated over them normally. The material is collected from each pan, weighed or measured, and then graphed to determine swath width, uniformity, and application rate. This same technique is used for all types of granular distributors.

Air-Flow Spreaders

Air-flow spreaders have the potential to make very uniform applications. The distribution points are typically every 3 to 5 feet. If every point is properly adjusted, these units should be less susceptible than spinner units to variations in distribution pattern due to wind and topography. Care should be taken to keep the metering mechanism clean and in good repair. Faulty or plugged feed delivery systems can adversely affect the dosage that is delivered to each distribution point. A thorough daily cleaning will help avoid this. Units should be operated statically long enough to completely dry all air passageways after cleaning.

Photo 8-5. Air-flow spreader.

Aerially Applied

Most nitrogen fertilizer is applied to rice aerially. Aircraft spreaders can do an excellent job but need to be carefully calibrated to ensure swath uniformity and that the correct swath width is being used. Workshops are held in Arkansas annually to help aerial applicators test and calibrate these spreaders. Measurement techniques very similar to those used on ground equipment are used. The major difference is the size and shape of the collectors. Generally, collectors are constructed on a steel skeleton with a cone-shaped fabric cover. The fabric absorbs the energy from the falling particles – helping to avoid bounce out.

Almost all state agencies and major forestry contracts now require aerial applicators to be tested and provide documentation on performance. This practice is becoming more common with farmer customers as well – to provide some assurance of quality prior to the job.

Aircraft equipment has improved dramatically in recent years. The most common swath width for prilled urea is about 78 to 85 feet when using an application rate of 100 pounds per acre. Swath widths typically narrow about 3 feet for each 25 pounds per acre increase in application rate. This is because there is an increased flow rate of material through a fixed air flow in the spreader. Each spreader has a maximum practical limit of material that can be transported with the available air – the intake area of the spreader is generally fixed.

Many spreaders reach a practical limit at application rates greater than 250 pounds per acre. Several new spreaders, with larger capacity, are beginning to show up in the Delta. These are capable of applying up to 350 pounds per acre in a single pass. Increasing flow rates above the practical limit of the spreader generally results in poor pattern uniformity. Applicators typically cut the swath width in half when the spreader limit is reached. This cuts the flow rate in half and provides a second coating of material. Two coats of fertilizer are very similar to two coats of paint – the overall application is more uniform.

Material Property Effects

Ground and aerial applicators do a much more uniform job of spreading seed than fertilizer. This is because seeds are all about the same size and shape – with almost no fine particles. The most important variable with seed applications, particularly with spinner and aerial spreaders, is use of the correct swath width. The swath width for seed varies with seed shape, density and size. Optimum swath widths differ very little for aerially-seeded rice. These are typically between 48 and 60 feet, with higher application rates and smaller equipment being on the low end.

Buying cheap fertilizer may not be a good way to reduce input costs if the fertilizer is not a uniform size. No application platform can uniformly spread materials with particles of many different sizes. The more fine particles or dust in a fertilizer mix, the poorer the spread pattern one can expect.

Segregation of sizes becomes a major problem with blended fertilizers. Segregation in the hopper may be avoided, or significantly reduced, if proper blending is done and the material is not allowed to cone during a transfer operation. Differences in spread widths of the blended materials will still occur if the individual components vary in size, shape and density.

General Recommendations

Chemical applications represent a large component of rice production costs. Work with your equipment or your applicator to ensure that the most accurate application possible is obtained. Improper application or off-target movement can turn an economical treatment into an expensive one. Always read and follow labels directions. Additional information on proper mixing of chemicals can be found here: https://www.uaex.edu/publications/PDF/FSA-2166.pdf

Chapter

9

Soil Fertility

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Nutrient management represents one of the most expensive inputs to a successful rice crop. Because of the large investment required, optimum management is critical to ensuring no more than what is economical is applied but, at the same time, sufficient amounts are applied to ensure profitable and sustainable yields. Many nutrients are necessary for optimum plant growth. Determining which are in sufficient quantity in the soil and which should be supplemented by fertilizer is the key to nutrient management. Either too much or too little is undesirable because the crop could be adversely affected. Therefore, research has focused on providing fertilizer recommendations that are economically, environmentally and agronomically sound. The following sections describe the recommendations and provide some of the research data that supports those recommendations.

Nitrogen

Nitrogen (N) is required by rice in the largest quantities of any nutrient, and it is typically not only the largest fertilizer input cost but the largest input cost for rice producers. Profitable rice grain yields are very dependent on proper and effective N fertilizer management. No other fertilizer nutrient presents a greater challenge to the rice producer than does the effective management of N fertilizer, and no other fertilizer nutrient can provide greater returns in increased rice yield for effective management. Nitrogen fertilizer is subjected to many N loss processes when it is applied to rice, and these N loss processes that operate in the soil-water environment can compete quite successfully with the young rice plant for the N fertilizer. Consequently, the appropriate N fertilizer management options available to the rice producer are based on our current understanding of the N behavior in the soil, before and after flooding, and the N uptake characteristics of the rice plant.

Nitrogen Fertilizer Rates

Two methods now exist to determine the proper N fertilizer rate for rice, the **Standard Method** and the **N-Soil Test for Rice (N-STaR)**. The Standard Method recommendation is based on cultivar, soil texture and previous crop. The Standard Method has worked well over the last four decades, but because it assumes all soils of a given textural class (i.e., clay or silt loam) require the same N rate, its use can result in under- or over-fertilization with N, even when the previous crop is taken into account. To improve N fertilizer rate recommendations for rice producers, the soil test N-STaR was developed that can measure the soil's ability to supply N and enable a prescription N fertilizer rate on a field-by-field basis. N-STaR is accurate and precise enough to allow for prescription N rates for different management or soil texture areas within a single field when grid-sampled properly.

Standard Method

Rice cultivars differ in the amount of N fertilizer required to produce optimum grain yields. The N rates listed in Table 9-1 are for a) rice grown in rotation after soybeans, b) rice grown on silt loam or sandy loam soil, c) optimum stand density and d) land that has been in cultivation for longer than five years.

If all four listed criteria have not been met, an adjustment of the early or preflood N rate is required.

Table 9-1. Recommended nitrogen rates and distribution for rice cultivars grown in Arkansas.

Cultivars	Single Preflood N Rate†	Rates and Distribution for Two-Way Split Application			
		Total N Rate	Preflood N Rate‡	Mid season N Rate††	Late Boot N Rate‡‡
		- - - - - - - - - Lbs N/Acre - - - - - - - - -			
CL151	100	**120**	75	45	--
Caffey, Della-2, Jazzman-2, Roy J	115	**135**	90	45	--
Cheniere, CL111, CL153, CL163, CL172, CL272, Cocodrie, Diamond, Francis, Jupiter, LaKast, Mermentau, PVL01, Taggart, Titan, Wells	130	**150**	105	45	--
RT CLXL4534, RT CLXL729, RT XL723	--	**120**	90	--	30
RT 7311 CL, RT CLXL745, RT Gemini 214 CL, RT XP753, RT XP760	--	**150**	120	--	30

† Conditions required for use of optimum single preflood N rate:) field can be flooded timely (<7 days); 2) preflood urea is treated with a recommended urease inhibitor that includes NBPT; or ammonium sulfate is used as the N source; 3) can maintain a 2- to 4-inch flood depth for at least 3 weeks following flood establishment, and 4) the preflood N must be applied uniformly across the field (no streaking).

‡ N rate for rice on silt loam soils following soybean in rotation. Rates may need adjustment based on factors below.

†† Apply midseason N in one application a minimum of 3 weeks after the preflood N application AND internode elongation has started; both conditions must be met to receive maximum benefit from the midseason N.

‡‡ Hybrids receive additional N at late boot rather than midseason. Refer to DD50 for proper timing of this application.

Management Key

Use the N rate adjustment rules for the **standard two-way split and optimum preflood** (formerly referred to as single preflood) application methods.

Adjustments in the preflood N rate will be needed for the following situations and are additive if more than one applies:

1. Increase early N by 30 pounds per acre if:
   - rice is grown on clay soils.
2. Increase early N rate by 20 pounds per acre if:
   - rice follows RICE in rotation.
   - rice follows COTTON in rotation
   - stand density for conventional cultivars is < 10 plants per square foot or hybrids is < 3 plants per square foot.
3. Increase early N rate by 10 pounds per acre if:
   - rice follows GRAIN SORGHUM in rotation.
   - rice follows WHEAT in rotation (double-crop).
   - rice follows CORN in rotation.
4. Decrease early N rate by 10 pounds per acre if:
   - rice follows SET-ASIDE or FALLOW that is not continuously tilled during the fallow period.
5. Use N-STaR or omit early N if:
   - rice follows FISH, LONG-TERM PASTURE or FIRST YEAR AFTER CLEARING in rotation. If N-STaR is not used, then continuously monitor the rice crop after flooding for signs of N deficiency and apply N fertilizer promptly if an N deficiency appears. No more than 45 pounds N acre should be applied into the floodwater during vegetative growth in any single application. Occasionally, a rice crop in these situations requires an N application at midseason of 45 pounds N per acre that should be applied between beginning internode elongation (panicle initiation) and ½ inch internode elongation (panicle differentiation). Beginning internode elongation and ½ inch internode elongation growth stages are indicated on the DD50 printout.

Nitrogen-Soil Test for Rice (N-STaR)

Different soils or fields have different levels of native soil N fertility and require different amounts of supplemental N fertilizer to optimize rice grain yields. The soil-based N test for rice, N-STaR, can measure a soil's ability to mineralize or supply N to the rice crop and prescribe an N fertilizer rate for the different cultivars of rice. N-STaR is a soil-based N test that quantifies the amount of N that will become available to the rice crop during the growing season. A unique attribute of N-STaR is that it measures a combination of simple organic-N compounds and NH_4-N contained in the soil. Organic-N is relatively stable in the soil and is not prone to the loss mechanisms of leaching and denitrification, but must be mineralized into NH_4-N prior to uptake and assimilation by plants. The two primary types of organic-N in the soil quantified by N-STaR are amino acids, such as glutamine, and amino sugars, such as glucosamine. These organic-N compounds reside in the soil and are found in the tissue of plant residues and soil microbes. Thus, N-STaR is site or field specific and is not influenced by the previous crop. However, even with N-STaR the cultivar being grown must be known for a recommendation because different rice cultivars require different amounts of N to maximize yield.

Three things have to be known and supplied for each field to use N-STaR: i) soil texture, ii) the cultivar being grown and iii) a soil sample taken to the proper depth. Accurate soil sampling is critical for N-STaR to give a proper N fertilizer recommendation. The soil sample must be taken from the effective rooting depth or nutrient uptake depth of the rice plant. Proper soil sampling depth is a key component of N-STaR's success and can be attributed to the effective rooting depth of rice. Arkansas research has shown rice roots may grow to a depth of 24 inches, suggesting that roots may take up nutrients present in the subsoil. The proper depth to sample is 0 to 18 inches for loamy soils and 0 to 12 inches for clayey soils using a proper soil sampling implement. Soil samples that are taken at less than the recommended depth for each soil texture will usually result in under-application of N fertilizer (Table 9-2) and less than optimal rice yields. Conversely, soil samples that are deeper than the recommended sampling depth will most likely result in N fertilizer recommendations that are greater than what is actually required to maximize yield, resulting in over-application of N fertilizer.

The N-STaR Soil Sample Bucket (Photo 9-1) is an essential component required to collect soil samples to the proper depth based on soil texture. This mechanized approach is a drastic improvement over the slide hammers used to take deep soil samples for nitrate-N in cotton and corn. It is imperative that the entire soil core be collected and packaged for analysis in order to get an accurate estimate of the potentially available soil N and a reliable N fertilizer recommendation. The N-STaR Soil Sample Bucket has several distinct advantages over the slide hammer, including: i) the use of a cordless drill rather than manpower, ii) the entire sample can be taken in a single core, iii) the ability to soil sample in a variety of soil moisture conditions and iv) the ease with which the soil can be collected and transferred to a 1 quart Ziploc® or similar quality sealable bag. Removal of soil from the probe is often difficult when using a slide hammer due to compaction and the risk of soil spillage. Refer to Arkansas Cooperative Extension Service fact sheet FSA2168, *N-STaR Soil Sample Bucket*, to obtain a detailed list of instructions on how to fabricate or purchase an N-STaR Sample Bucket.

Table 9-2. **N-STaR soil test values, predicted nitrogen fertilizer rates and the associated application errors as influenced by soil sampling depth for a silt loam soil.**

Sample Depth	Category	N-STaR Value	N Rate Recom-mendation	Application Error†
inches		mg N kg soil $^{-1}$	N fertilizer rate (lbs N/A)	
0-18	Correct Depth	100	115	0
0-12	Too Shallow	135	50	-65
0-6	Too Shallow	150	20	-95
0-24	Too Deep	80	150	+35

† Application error refers to the amount of nitrogen fertilizer either under-applied or over-applied when compared to the nitrogen fertilizer recommendation from the correct sampling depth.

Photo 9-1. **N-STaR soil sample bucket, soil auger and drill.**

After collecting soil samples in the field, the second and equally important part of submitting a quality soil sample is proper packaging prior to shipment. Current recommendations require 10 samples per field, which should be collected and placed in 10 individual 1-quart sealable bags and then grouped in either a larger sealable bag or grocery sack. Proper packaging and grouping of soil samples by field can eliminate some shifting during shipment and also allows identification of samples if the writing on bags is smeared or removed. When preparing samples for shipment, do not place more than 40 samples in a single box as the weight can cause damage to the box and soil samples. Please remember to package samples tightly and fill in any extra space with newspaper or packing material. If samples are not secure during shipment, shifting and sliding can cause bags to split. Do not use soil sample boxes to aid in packing and shipping as they often result in soil spillage. Spilled samples will not be analyzed because they could lead to an erroneous soil test and incorrect fertilizer recommendation. Send samples to the N-STaR Laboratory, 1366 W. Altheimer Drive, Fayetteville, Arkansas 72704. For more information, contact the lab at 479-575-6752 or nstarlab@uark.edu.

The purpose of N-STaR is to provide field-specific N rates that will ensure the proper N rate is being applied on a field-by-field basis to achieve optimum rice yields. Nitrogen fertilizer rate recommendations with N-STaR will come from relative grain yield (RGY) goal calibration curves, as shown in Figure 9-1 and Table 9-3, and give the rice grower options as to how much N fertilizer to apply based on the grower's available finances and fertilization philosophy.

Management Key

Correct identification of the soil texture and soil sampling depth are important to ensure the proper N-STaR N rate recommendation is provided. Remember that the recommended sample depth is 0-12 inches for clay soils and 0-18 inches for loamy soils.

The success of N-STaR for rice has been largely influenced by the high and consistent N uptake efficiency, which is directly tied to proper flood management. **Conditions critical for use of the N-STaR technology are: the field can be flooded timely, the urea is treated with the urease inhibitor NBPT (N-(n-butyl) thiophosphoric triamide) or ammonium sulfate is used, unless the field can be flooded in two days or less for silt loam soils and seven days or less for clay soils, and a 2- to 4-inch flood depth is maintained for at least three weeks following flood establishment.**

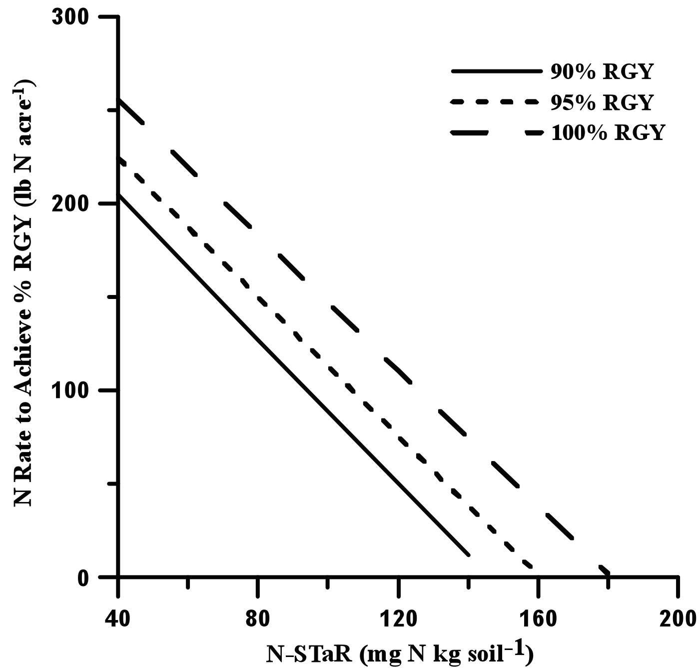


Figure 9-1. Nitrogen fertilizer calibration curves for rice grown on silt loam soils based on relative grain yield (RGY) goal.

Table 9-3. N-STaR soil test values and predicted nitrogen fertilizer rates to achieve 90, 95 and 100% relative grain yield (RGY) goal for various fields with loamy soils.

Field	N-STaR Soil Test Value	Yield Goal (% RGY) Economic (90%)	Optimum (95%)	Above Optimum (100%)
	mg N kg soil $^{-1}$	N fertilizer rate (lbs N/A)		
1	136	20	45	80
2	118	60	80	115
3	110	70	95	130
4	98	95	120	150
5	80	130	150	185
6	70	150	170	200
7	63	160	180	215

The goal of the N-STaR program is to provide field-specific N rates that will maximize productivity and profitability in regard to one's N-fertilizer program. Routine soil analysis for phosphorus (P), potassium (K), sulfur (S) and zinc (Zn) availability should continue to be a producer priority when using N-STaR. Optimizing N fertilizer inputs and maximizing rice yields using N-STaR can only be accomplished when other nutrients such as P, K, S and Zn are sufficient for optimal rice growth. **N-STaR-based N rate recommendations are for delayed, flood rice only** and have not been evaluated for use on water-seeded continuously flooded rice or furrow-irrigated rice.

Management of N fertilizer for maximum uptake efficiency by the rice crop varies with the cultural system, cultivar, soil texture, soil moisture and several other factors. These factors are discussed in more detail in the following text.

Dry Seeding

Two options are available for applying N fertilizer to rice: the **standard two-way split**, a large early (preflood) N application followed by a midseason or late boot N (hybrids only) application, or the single, **optimum preflood** N application. Several options are available for managing the N in a dry-seeded cultural system, and all options are viable if performed using the defined guidelines. However, correct management of the preflood N is critical since a rice crop's potential grain yield is determined by the preflood N.

The standard **two-way split application** is a very effective application method and may be the most practical N fertilization method for a large percentage of Arkansas rice fields. This method should be used on fields where limited irrigation capacity, large field size or another factor compromises the timeliness of establishing the flood across the field and maintaining it. Conditions critical for use of the **optimum preflood** N application method are: the field can be flooded timely, the urea is treated with the urease inhibitor NBPT or ammonium sulfate used, unless the field can be flooded in two days or less for silt loam soils and seven days or less for clay soils, and a 2- to 4-inch flood depth is maintained for at least three weeks following flood establishment. Research indicates that when the preflood N is improperly managed, resulting in poor plant growth, midseason N applications are not capable of recovering the entire lost yield potential. Regardless of the N management system used (two-way split or optimum preflood) proper management of the preflood N is essential to maximize N fertilizer uptake and minimize N losses. Nitrogen is stored in the plant stem and leaf tissue during vegetative growth following the preflood N application. This stored N is transported and used within the plant later in the season during periods of peak N needs, such as during grain fill. If the preflood N is mismanaged and adequate plant growth during the vegetative growth stage does not occur, crop yield potential suffers. As a general rule, when more than 45 pounds of N per acre is needed at midseason, yield potential has likely been lost.

When the standard two-way split N application method is used on hybrids, the second N application should be applied between late boot and beginning heading. Application of N later than beginning heading can damage flowering panicles and lead to yield loss. The 30 pounds of N per acre late boot application is recommended only for hybrids to minimize lodging and occasionally increase grain and milling yields. The greatest benefit of the late boot N application in minimizing lodging of the hybrids has been observed when they are grown on soils that are prone to waterlogging in the fall and, thus, do not allow for a timely harvest. Table 9-1 provides rates for the two-way split application method.

A single, **optimum preflood** N application followed by a visual midseason evaluation is recommended for fields with excellent irrigation capability for the conventional, pure-line varieties, not the hybrids. The optimum preflood method should not be used with the weaker-strawed pure-line varieties. Research has consistently shown that a single application of an optimum amount of N preflood results in equal or better yields than the traditional split application methods and usually requires less total N to achieve maximum yields.

The preflood N is critical for determining potential grain yield regardless of whether split or single applications are used. The number of panicles (heads) and the number of grains per panicle are determined by the preflood N application. The stiff-strawed, early-maturing cultivars do not respond to midseason N applications like their taller, longer-season predecessors and, at best, the midseason N application results in only a 10 to 15 bushel per acre yield increase. Because yield potential is determined prior to mid-season, yield cannot be completely recovered with midseason N if the preflood N rate is too low or if the preflood N has been mismanaged due to untimely flood application or loss of flood within three to four weeks of preflood N application.

Milling yield (percent head rice) also benefits from proper N fertilization. In general, the percent head rice is highest when maximum grain yield is produced. The preflood N rate for the optimum preflood method can be calculated for each rice cultivar by simply adding 15 to 25 pounds of N per acre to the preflood rate recommended for the two-way split application method in Table 9-1. Where management practices allow, use the optimum preflood N application since this method has consistently produced the highest grain and milling yields in replicated research.

Early N Application and Management

The early N application (Table 9-1) (65 to 100 percent of the total N rate) should be applied as an ammonium N source (Table 9-4) onto dry soil immediately prior to flooding, termed preflood N, near the 4- to 5-leaf growth stage (Table 9-5 and Figure 9-2). There is not an exact time to apply the early N but actually a window of a couple of weeks that the early N can be applied. The DD50 printout gives the window of dates for early N application. Once the early N is applied, flooding should be completed as quickly as possible, preferably in two days or less for loamy soils and seven days or less for clays. The flood incorporates the N fertilizer into the soil where it is protected against losses via ammonia volatilization and/or nitrification/denitrification as long as a flood is maintained. Maintain the flood for at least three weeks to achieve maximum uptake of the early applied N (Table 9-6).

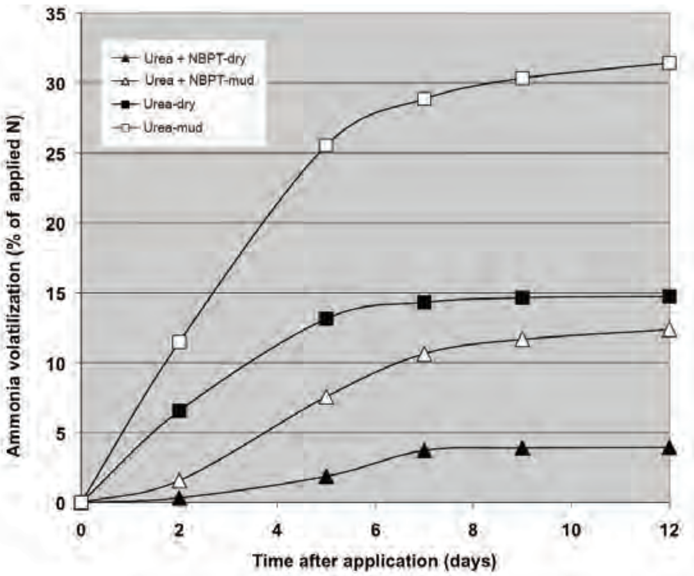
Management Key

The preflood N rate and efficiency of uptake determine overall grain yield potential. Management of the preflood N is critical for achieving maximum yields.

For the preflood N application, an ammonium N source, such as urea, NBPT-treated urea or ammonium sulfate is preferred over an N fertilizer containing nitrates (i.e., N solution) (Table 9-4).

Table 9-4. Nitrogen fertilizer sources.

N Source (in order of preference)	Remarks
Early Season (65% to 75% of total N requirement)	
Urea – 46% N	High N analysis, high N loss via ammonia volatilization if applied to a silt loam soil and not incorporated by floodwater in two days or less or a clay soil and not incorporated in seven days or less.
NBPT treated Urea – 46% N	High N analysis, cost slightly more than urea, minimal N loss via ammonia volatilization if applied to soil.
Ammonium Sulfate – 21% N, 24% S	Low N analysis, high cost, minimal N loss via ammonia volatilization if applied to soil. Good source on soils that also require sulfur (e.g., sandy soils).
Urea ammonium nitrate solution (UAN) – 32% N	Medium N analysis, cost similar to urea, high N loss via ammonia volatilization if applied to soil and not incorporated by floodwater in two days or less and high N loss via denitrification from nitrates in the solution. (Not recommended for preflood N fertilization.)
ESN (Polymer-coated urea) – 44% N	The ESN fertilizer is urea coated with a permeable, plastic coating that allows water to enter, dissolve the urea granule and the urea solution to diffuse back through the coating where it is available for plant uptake. The release rate is affected mostly by temperature. Approximately 40 days is needed for > 80% of the N to be released during the temperatures that are common during April and May. Slightly higher cost per ton than urea. Not recommended for preplant, preflood or postflood N fertilization.
Midseason (25% to 35% of total N requirement)	
Urea – 46% N	High N analysis, widely available, minimal loss at midseason.
UAN Solution – 32% N	Even distribution, cost similar to urea, ammonia volatilization loss greater than urea at midseason.



Source: Norman et al., 2006. p. 290-297. *B.R. Wells Rice Res. Studies 2005*. Ark. Rice Res. Ser. 540.

Figure 9-2. Ammonia volatilization losses when urea and NBPT-treated urea were applied to a dry or muddy soil five days prior to flooding.

Compared to UAN, granular (or prilled) urea applied at preflood results in greater N uptake and grain yield (Table 9-7). Nitrogen solution or UAN solution contains 25 percent nitrate, which will be lost after flooding via denitrification; therefore, its use as a preflood N fertilizer is not recommended. Urea or ammonium sulfate are excellent fertilizers for the early preflood N application; however, urea is much cheaper per pound of actual N compared to ammonium sulfate and equal in effectiveness if incorporated with the flood in less than two days for loamy soils and seven days for clay soils.

Greater than 20 percent of the urea-N applied to a dry silt loam soil can be lost via ammonia volatilization in five days (Figure 9-3) and result in a significant loss in rice grain yield (Table 9-8). The use of ammonium sulfate or urea treated with the urease inhibitor NBPT (N-(n-butyl) thiophosphoric triamide) can reduce ammonia volatilization losses and maintain rice grain yields equivalent to when urea is used and a flood obtained across the field in a single day. Consequently, if greater than two days is required to get the flood-water across a silt loam field, then ammonium sulfate or NBPT-treated urea should be used. Ammonia volatilization of urea from clay soils (Figure 9-4) tends to be less than from silt loam soils, and urea (no NBPT) is recommended on clayey fields when seven days or less is required to flood. Ammonium sulfate or NBPT-treated urea should be applied to clay soils when more than seven days is required to establish a flood. Urea treated with NBPT is usually cheaper than ammonium sulfate. The urease inhibitor NBPT is sold under the trade names *Agrotain*® (Koch Agronomic Services LLC), *Arborite*® (Weyerhaeuser and Gavilon Fertilizer LLC), *Factor* (Rosens Chemical Company) *N-FIXX*™ (Helena Chemical Company), *N-Veil*

Table 9-5. Influence of preflood N source and soil moisture conditions on Wells rice grain yields at the Rice Research and Extension Center in 2004.

N Sources†	Dry Soil	Muddy Soil
	Grain Yield (bu/A)	
Urea	195	161
Urea + NBPT	199	182
Ammonium Sulfate	193	180

† All N sources applied two days prior to flooding at the 4- to 5-leaf stage.

Source: Norman et al., 2006. p. 290-297. *B.R. Wells Rice Res. Studies 2005*. Ark. Rice Res. Ser. 540.

Table 9-6. Percent N uptake by rice at different times after N application.

N Application Timing	Sampling Period Days After Application	Plant N Uptake % of Applied N
Preflood†	7	11
	14	27
	21	63
	28	65
Midseason‡	3	70
	7	67
	10	76

† Urea applied on a dry soil surface and flooded immediately.
‡ Urea applied into the flood.

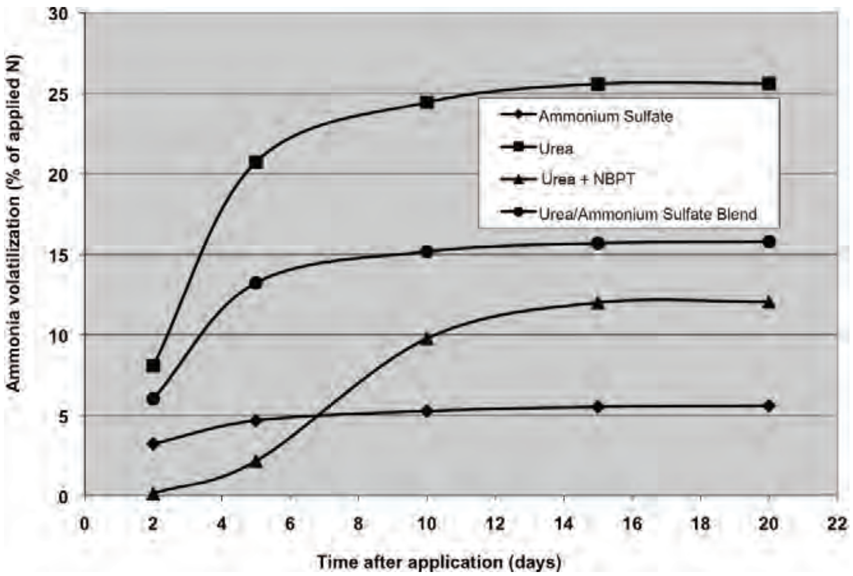
Source: Wilson et al., 1989. *SSSAJ* 53: 1884-1887.

Table 9-7. Comparison of urea and urea ammonium nitrate (UAN) as N sources at three application timings in rice.

N Source	Time of Application: Preflood†	½" IE‡	½" IE + 10d	Grain Yield
	% of applied N			bu/A
Urea	66	77	82	154
UAN	41	64	65	134

† 75 lbs N/A preflood
‡ 30 lbs N/A applied for each midseason [½" IE and ½" IE + 10 days].

Source: Wilson et al., 1994. *SSSAJ* 58:1825-1828.



Source: Norman et al., 2009. *Soil Sci. Soc. Am. J.* 73:2184-2190).

Figure 9-3. Ammonia volatilization losses when several N sources were applied 10 days prior to flooding.

Table 9-8. Influence of N fertilizer sources applied at 1, 5 and 10 days prior to flooding on the grain yields of Wells rice in 2003.

N Sources†	N Rate	Grain Yield Application Time Prior to Flooding		
		1 day	5 days	10 days
	lbs N/A	bu/A		
None	0		96	
Urea	120	187	160	154
Urea + NBPT	120	188	182	175
Ammonium Sulfate	120	181	178	171
Ammonium Sulfate + Urea	120	179	166	161

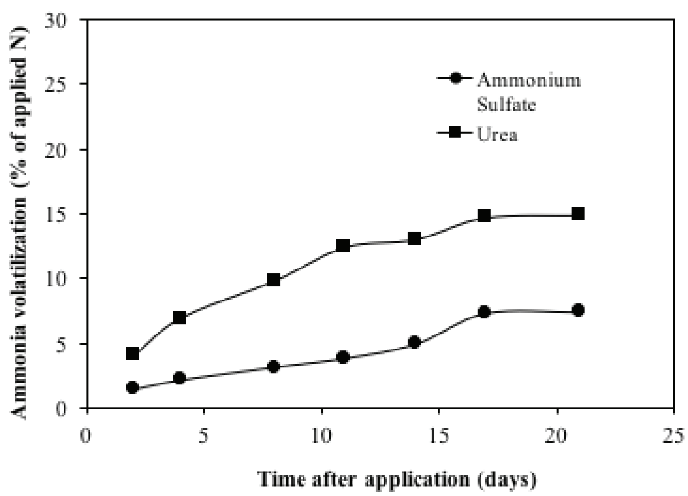
† All N sources applied to a dry soil at the 4- to 5-leaf stage.

Source: Norman et al., 2009. Soil Sci. Soc. Am. J. 73:2184-2190.

(Invictus Crop Care, LLC) and *NitroGain*® (Arclin INC.). (See FSA2169, *Nitrogen Fertilizer Additives*). A typical rate of NBPT treatment on urea prills is 4 quarts per ton of urea of a product that contains ~20 percent NBPT or 3 quarts per ton of a product that contains ~25 percent NBPT. Blending of urea and ammonium sulfate can reduce ammonia volatilization losses and minimize grain yield reductions. However, a urea-ammonium sulfate blend is not as effective as NBPT-treated urea in reducing ammonia volatilization or in maintaining rice grain yields and the blend costs more (i.e., per unit of actual N) than NBPT-treated urea. Ammonium sulfate, urea-ammonium sulfate blends, or other N plus S-containing fertilizers are best utilized when there is the potential for a sulfur (S) deficiency or when rice is grown on permeable soils (sands and sandy loams) that typically suffer from N and S deficiencies.

Management Key

If the urea applied preflood cannot be incorporated with the flood in two days or less for silt loam soils and seven days or less for clay soils, ammonia volatilization loss can be significant (Figure 9-2) and the use of NBPT-treated urea or ammonium sulfate is warranted (Table 9-4).



Source: Griggs et al., 2007. *Soil Sci. Soc. Am. J.* 71:745-751.2007).

Figure 9-4. Ammonia volatilization loss of urea and ammonium sulfate when applied to a Perry clay.

Wet (muddy) soil conditions can prohibit rice farmers from applying the early N onto a dry soil at the 4- to 5-leaf growth stage. Because there is a window of a couple of weeks to apply the preflood N, every effort should be made to apply the early N onto a dry soil surface. However, if wet conditions persist and the preflood N cannot be applied during this window onto a dry soil, use NBPT-treated urea and apply the preflood N onto the muddy soil, but wait until the soil dries before flooding to minimize ammonia volatilization loss (Figure 9-2 and Table 9-5). The flood will not be able to incorporate the urea below the soil surface if the soil is not dry, and ammonia volatilization will not cease when the soil is flooded. **Do not, for any reason, apply the large preflood N into the flood in a single application.**

Application of the large, early N rate into the flood in a single application is very inefficient. Since the N is not incorporated into the soil, most of the N is lost via ammonia volatilization within seven to ten days after application, before the young rice can use it; increasing the N rate will not fully compensate for the amount of N lost. If excessive rainfall has flooded the field at the 4- to 5-leaf stage and the preflood N has to be applied into the floodwater, then it is best to increase the early N rate and split-apply the preflood N every week in increments of 30 to 45 pounds of N per acre per application until internode elongation.

Management Key

Do not, for any reason, apply the large preflood N into the floodwater in a single application.

Polymer-coated urea marketed as Environmentally Smart N (ESN) is an excellent N fertilizer for preplant application to upland crops like corn and cotton, but is not currently recommended for use at any growth stage (preplant, flushed in, preflood or postflood applications) in flood-irrigated rice. Research has shown that ESN applied preplant or preflood (3- to 5-leaf stage) to rice grown in the direct-seeded, delayed-flood production system is not a suitable alternative to urea applied preflood and managed properly.

Lab and field studies suggest most of the urea in ESN is released in about 40 days after being incorporated into the soil. As the urea-N is slowly and continuously released from the polymer, the urea is converted to ammonium and eventually to nitrate, which may be lost quite rapidly via denitrification when rice fields become saturated from excessive rainfall, flush irrigation or establishing the permanent flood. Research with water-seeded rice or furrow-irrigated rice has not been conducted, but ESN may be of greater utility in these rice production systems which are used on only a small percentage of the Arkansas rice-producing area.

Table 9-9. Influence of nonuniform N distribution (streaking) on rice grain yield.

Preflood N % Distribution	Actual N lbs Distribution	Grain Yield
% : %	lbs N : lbs N	bu/A
100 : 100	75 : 75	170
125 : 75	94 : 56	161
150 : 50	113 : 37	160
175 : 25	131 : 19	146
200 : 0	150 : 0	139

Source: Helms et al., 1987. *Univ. Ark. Farm Res.* 36(2):9.

The large N rates required at the early N application time can be difficult to apply evenly, and streaking may result. Streaking is not only unpleasing to the eye but can cause significant yield loss (Table 9-9). The best way to avoid streaking is to use an aerial applicator who knows exactly how to operate the aircraft when applying heavy rates of fertilizer. All aircraft have a maximum material flow rate that limits their useful swath width. Large aircraft and spreaders may be able to apply heavy rates of materials with little or no sacrifice in distribution uniformity. The usable swath width of all aircraft decreases as the application or flow rate increases. Double flying (using one-half the desired application rate and flying at one-half the optimum swath width for that application rate) may be used for most aircraft applications when the maximum practical flow rate is exceeded. Double flying typically results in more uniform application of N fertilizer.

Management Key

If the urea applied preflood cannot be incorporated with the flood in two days or less for loamy soils and seven days or less for clayey soils, NBPT-treated urea or ammonium sulfate should be used.

An alternative method of reducing the chance of streaking is to split the early N into two applications. Apply about one-third of the early N rate onto dry soil immediately prior to flushing at the 2- to 3-leaf stage and apply the remainder just before flooding. Always incorporate the N with water when N is applied preflush (Table 9-10). The alternative method is only recommended when the early N rate is 90 pounds of N per acre or more. The early split

Table 9-10. **Nitrogen uptake efficiency, using an N-15 tracer, of several N rates and application timings.**

Treatment†	N Use Efficiency		Grain Yield
	lbs N/A	% N	bu/A
30 lbs‡ PPI + 90 lbs PF	12	40	176
30 lbs‡ PFS + 90 lbs PF	17	57	181
30 lbs PPI + 90 lbs‡ PF	72	80	179
60 lbs‡ PPI + 60 lbs PF	20	33	158
60 lbs‡ PFS + 60 lbs PF	32	53	166
60 lbs PPI + 60 lbs‡ PF	47	78	160
120 lbs‡ PPI	32	27	125
120 lbs‡ PF	91	76	177
90 lbs PF + 30 lbs‡ 1 wk POF††	4	13	158
90 lbs PF + 30 lbs‡ 2 wk POF	6	20	163
60 lbs PF + 60 lbs‡ 1 wk POF	8	13	142
60 lbs PF + 60 lbs‡ 2 wk POF	9	15	146

† PPI = Preplant Incorporated; PF = Preflood; PFS = Preflush; POF = Postflood (in water).
‡ Indicates the nitrogen application that was labeled with N15 tracer.
†† Postflood treatments applied into the water one or two weeks (wk) after flooding at the 4-to 5-leaf stage.

Source: Norman et al., 1994. p. 138-145. *Ark. Rice Res. Studies 1993.* Ark. Ag. Exp. Sta. Res. Ser. 439.

application applied a week or two before permanent flooding is at greater risk to nitrification/denitrification loss and ammonia volatilization loss if not flushed in and, therefore, is not used as efficiently as when the N is applied immediately before flooding. Preplant incorporation of all or a portion of the early N to reduce streaking is a poor alternative and is not recommended. Additionally, applications of a portion of the large preflood N into the flood water a week or two after flooding at the 4- to 5-leaf stage is taken up poorly and not recommended.

Nitrogen applied immediately prior to flooding or preflood has resulted in the highest yields and greatest N fertilizer use efficiency in research tests. Therefore, if N fertilizer can be applied evenly, the early N should be applied preflood and not preflush, and most certainly not preplant or postflood during the vegetative stage. However, if rice becomes yellow and deficient of N during the vegetative growth stage, then N fertilizer should be applied immediately and in sufficient amounts to correct the deficiency. Never wait until midseason to correct a deficiency that occurs during the vegetative growth stage or large yield reductions can result. If the rice turns light green or yellow during the reproductive growth stage, there is no need for additional N fertilization because the yield has already been set and this is not unusual.

Management Key

If rice becomes yellow and deficient of N during the vegetative growth stage, N fertilizer should be applied immediately and in sufficient amounts to correct the deficiency, but not if this occurs during reproductive growth after internode elongation.

Midseason N Application and Management

Fertilizer N applied at midseason, at the proper times and in the proper amounts, is taken up with a 65 to 80 percent efficiency (Tables 9-6 and 9-7). Ideally, midseason N rates should not exceed 45 pounds of N per acre. In general, when rates greater than 45 pounds of N per acre are needed, the preflood N rate was considerably inadequate or the preflood N was mismanaged. To take full advantage of the midseason N, the preflood N has to be applied at the correct rate and managed correctly. Notice in Table 9-11 how much better the yield of rice at the NEREC responded to midseason N applied at beginning internode elongation (IE) plus seven days or later when the greater preflood N rate of 90 pounds of N acre was applied compared to a preflood N rate of 45 pounds of N per acre.

Midseason N application should be timed according to plant development (Table 9-1); that is, applied no earlier than beginning IE (Photo 9-2). Recent research has indicated the new varieties do not always respond to midseason N, especially if an adequate rate of preflood N has been applied. Notice in Table 9-11 a negligible yield increase was obtained at PTRS when 90 pounds of N per acre was applied preflood. Results also indicate when there is a response to **midseason N, the application time window appears to be at least two weeks wide** and the application time is later than beginning IE or ½ inch IE (that is, beginning IE + 7 days) depending on when the preflood N fertilizer was applied. Notice in Table 9-11 that the best yield response to midseason N was when the time between the preflood N and midseason N was at least three weeks. **Thus, the first or only**

Photo 9-2. **Rice stems showing internode elongation (IE). The stem on the far left is at the green ring stage (note the green band above the top node), the stem in the middle is at ½ inch IE, and the stem on the far right is at 1 inch IE.**

midseason N application should be applied no earlier than beginning IE and at least three weeks after the preflood N application. Both of these conditions have to be met to obtain the full grain yield benefit of the midseason N application. If a second midseason N application is required, it should be applied seven days after the first.

The DD50 program provides estimated times for midseason applications. Midseason N can be applied into the flood because, by BIE, the plant has developed an extensive root system near the soil surface and is growing rapidly. Research indicates that N applied at midseason is taken up by the rice plant within three days (Table 9-6). The smaller amount of N, coupled with the rapid rate of N uptake by the rice plant at midseason, enables the N to be applied into the flood without the large amount of N loss that is associated with applying the preflood N into the flood during the vegetative growth stage. The standard two-way split application (preflood-midseason) has the midseason N applied at a rate of 45 pounds of N per acre no earlier than beginning IE and three weeks after the preflood N application (Table 9-1).

Application of midseason N rates > 60 pounds of N per acre should be applied in split applications made seven days apart with the first applied no earlier than beginning IE and at least 3 weeks after the preflood N application. When >60 pounds of N per acre are needed at midseason, only a portion of the lost yield can be regained. **Thus, one should apply the correct preflood N rate and manage the preflood N correctly so no more than 0 to 45 pounds of N per acre are needed at midseason to maximize yield.**

To maximize hybrid rice yields and minimize lodging, the N fertilizer should be applied preflood and at the late boot stage (Table 9-1). Consequently, N should not be applied to hybrid rice at midseason unless N deficiency develops prior to late boot. The late boot N application to hybrid rice can, in some instances increase grain and milling yield, but its main purpose is to reduce lodging. Thus, hybrid rice should have the

Table 9-11. **Influence of preflood N rate and midseason (MS) N application time relative to the preflood N application time on rice grain yields.**

MS N Timing†	Grain Yield Location/Preflood N Rate				
	NEREC		PTRS		RREC
	45 lb N /A	90 lb N/A	45 lb N/A	90 lb N/A	
	bu/A				
No MS N	139	170	149	179	192
BIE‡	155	184	152	183	199
BIE + 7 days††	158	203	162	181	196
BIE + 14 days	157	196	163	185	201
BIE + 21 days	162	208	163	182	204

† BIE = beginning internode elongation; 45 lb N/A applied at midseason.

‡ Note: BIE N applied 15, 17 and 14 days after preflood N at the Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS) and the Rice Research and Extension Center (RREC), respectively.

†† BIE + 7 days is analogous to ½ inch IE.

Source: Norman et al., 2014. p. 303-310. B.R Wells Ark. Rice Res. Studies 2013. Ark. Rice Res. Ser. 617.

second N application applied at the late boot stage between full boot and beginning heading. Application of N later than beginning heading can damage flowering panicles and lead to yield loss.

Management Key

Midseason N can be applied in either one or two applications with the first midseason N application made between beginning internode elongation and ½ inch internode elongation.

Determining Midseason N Using Trimble GreenSeeker

The Trimble® GreenSeeker® handheld allows producers and consultants the ability to make objective decisions on midseason N management in rice. This sensor uses NDVI, or Normalized Difference Vegetation Index, which can be used to gauge the relative N fertility of rice (optimal or suboptimal).

To properly use GreenSeeker in rice, you must first establish a Reference Plot (minimum 5' x 5' area) in each field prior to the establishment of the permanent flood. The Reference Plot should have 50 to 100 pounds of N per acre more than the producer's preflood N rate. This is equivalent to 30 to 60 grams of urea over the 5' x 5' area (or ¼ to ⅓ of a standard measuring cup). The Reference Plot provides the user with a GreenSeeker reading from an area with maximum fertilizer-N uptake to compare with the producer practice. The larger the field, the more Reference Plots needed – i.e., a minimum of one Reference Plot per 50 acres.

To determine midseason N needs using the GreenSeeker, readings should be taken after Green Ring AND no earlier than 3 weeks following preflood N incorporation. Take readings from the Reference Plot and divide by the average of readings taken across the field. If the resulting value is greater than 1.15 then there is more than a 50% chance of a response to midseason N and it is recommended to make a midseason N application of 45 pounds N per acre (100 pounds urea per acre).

When taking GreenSeeker readings throughout the field, it is preferred to take a minimum of 10 readings. Each reading should consist of fully depressing the trigger and holding while walking 10 steps. Once the trigger is released, the resulting number on the handheld will be the average of the area covered.

GreenSeeker readings are no longer valid once plants reach the late boot stage of rice development (flag leaves fully exserted). Readings should not be taken from areas with thin stands. In thin stand areas, the resulting GreenSeeker reading will be artificially low due to the sensor reading from areas with no rice.

Table 9-12. Guide to rice midseason N applications using GreenSeeker (GS).

Reference Plot GreenSeeker Average	Apply Midseason N if Field GreenSeeker Reading is Less Than
0.80	0.70
0.75	0.65
0.70	0.61
0.65	0.56

Application recommendation based on greater than 50% chance of response to midseason nitrogen application.
Valid for both varieties and hybrids.

Photo 9-3. Reference plot with additional N showing darker green color compared to surrounding field.

Water Seeding – Pinpoint Flood

The fundamental principles of N fertility are the same regardless of whether rice is dry- or water-seeded, but the methods used to attain efficient uptake of the early N application are quite different. In water-seeding, the early N must be applied as an ammonium-N source onto the dry soil preplant and mechanically incorporated (PPI, 2 to 4 inches). The flood should be established immediately after N application/incorporation to minimize nitrification. Surface application of N followed by flood establishment for water-seeding does not adequately incorporate the N and prevent loss, in contrast to preflood N applications made in the dry-seeded, delayed-flood system. This is because in the dry-seeded, delayed-flood rice system the preflood N is applied at or around the 4- to 5-leaf growth stage and takes only three to four weeks to be taken up, whereas in water-seeded rice the N is applied around seeding and takes seven to eight weeks to be taken up.

Because of this long time period between application and plant uptake, the early N must be stored in the soil for a longer period of time before the rice crop can use the early N. Therefore, it is very important that the early N be incorporated deep and the flood maintained throughout the vegetative growth stage. If the soil does not stay saturated (flooded), the fertilizer N can undergo nitrification during the unsaturated periods and be lost via denitrification upon reflooding. With the pinpoint flooding method, the field must remain saturated when the field is drained for pegdown. One advantage of PPI N application is that early N can be applied with ground equipment, which may potentially reduce streaking and application costs. Two alternative methods of early N application for water-seeded systems include N application: i) when the field is drained for pegdown or ii) after draining at the 5-leaf to early tillering stage. These alternative methods have been used successfully by several Arkansas growers.

Based on field experiences, incorporate only the early preflood N rate recommended for the cultivar (Table 9-1). Regardless of the preflood N rate, supplemental N has usually been required in water-seeded Rice Research Verification Program fields. The need for supplemental N, either during active tillering or at midseason, is highly likely in water-seeded fields. Water-seeded rice should be closely monitored for signs of N deficiency, and if N deficiency occurs, N should be applied immediately.

Conservation or No-Till Systems

No-till dry-seeded, delayed-flood rice should have the N managed in the same manner as conventional-till dry-seeded, delayed-flood rice. Research conducted on silt loam and clay soils found no significant difference between the two tillage systems as concerns the N uptake efficiency of rice. However, if there is a substantial amount of plant residue (previous crop or weedy vegetation), extra N in the amount of 10 pounds of N per acre should be added to the preflood N rate to compensate for N losses due to ammonia volatilization and the extra N required to decompose plant residue.

No-till water-seeded rice is not an efficient N management system. Incorporation of the early N with the flood does not move the N deep enough into the soil to prevent substantial loss for the seven to eight weeks required for water-seeded rice to take up the early N. Spoon feeding the rice with biweekly top-dress N applications typically requires about 25 percent more N fertilizer and may still produce lower than normal yields. One viable alternative for the no-till water-seeded system is to knife anhydrous or aqua ammonia 4- to 6-inches beneath the soil surface prior to planting. This is not a common practice in the southern rice belt but is the standard practice for N fertilization of water-seeded rice in California. Another possible option is to drain and dry the field at the 4- to 5-leaf stage, apply the N fertilizer onto a dry soil and then reflood.

Soil Sampling and Soil Analysis

There are four steps to any soil-testing program including soil sampling, soil analysis, data interpretation and implementation of recommendations and management of soil-test information. Each step is critical in obtaining optimum fertilizer and lime recommendations. However, the most critical step in the process of soil sampling is collecting soil samples that accurately represent the variation of soil properties within fields. **Appropriate use of soil-test results requires that one understand that the soil-test nutrient (e.g., P, K and Zn) values are simply an 'availability index' and not an absolute value of soil nutrient content or plant-available nutrients.**

Soils are inherently variable between and within fields. **The recommendations received from a soil-testing program are no better than the sample that was collected to make those recommendations.** Therefore, correct soil-sampling procedures should be followed so that soil-test results for lime and other nutrient recommendations are representative of the entire field. When using the field-average method, collect composite soil samples from the area near the water inlet, the center and the bottom portions of the field, as well as areas that differ in soil series, soil texture, topography and crop productivity within these locations.

Management Key

One composite soil sample should represent no more than 20 acres.

Composite samples near water inlets should represent only 5 to 10 acres. Each composite sample should contain soil from 15 to 35 individual soil cores taken to a depth of 4 inches while following a zigzag pattern within each sample zone. Individual cores should be placed in a clean plastic bucket and thoroughly mixed. A subsample of this soil represents one composite sample, which will be submitted to the soil-test laboratory. Collecting an inadequate number of soil cores (< 15 to 35) per composite sample may compromise the accuracy of soil-test results by over- or underestimating the true field mean.

Soil samples may also be taken on grids representing 2.5 to 5.0 acre blocks within each field. Grid sampling improves the soil-testing process because composite samples are collected from numerous areas within the field and less area is represented by each sample. Thus, a "picture" can be made that depicts the variability within the field. Grid sampling and variable rate application equipment are highly recommended for lime application to fields with rice in the rotation. When grid sampling is performed, collect eight to ten soil cores per composite sample.

Regardless of whether soil samples are collected using the field-average, zone sampling or grid sampling method, obtaining cores from a uniform sample depth of 4 inches is critical. Soil-test based recommendations for P, K and Zn are based on a 4-inch sample depth. Collecting samples from shallower or deeper soil depths will likely result in over- or under-estimation of soil nutrient availability index values, respectively. Sample depth is highly important because P, K and Zn are relatively immobile nutrients and become stratified such that the concentration is greatest near the soil surface and decreases with increasing soil depth. Stratification of these immobile nutrients is greatest in no- and reduced-tillage systems. The ability to collect soil samples from the appropriate soil depth is influenced by the soil conditions at the time of sample collection. To facilitate uniform and unbiased sampling, soil samples should be collected when the soil is neither too dry nor too wet.

The best time to collect soil samples is considered to be during the winter and early spring (December, January, February, March and April) as soil-test recommendations for P, K and Zn are based on samples collected during this period. Soil-test results may show significant variability across time. Although temporal variability may not always follow a predictable pattern, samples collected in the early fall (October and November) often have different soil-test K values than samples collected in January through April. Soil-test P tends to be more consistent across time than soil-test K. Soil pH may also fluctuate 1.0 pH unit during the year with the tendency to be highest in the winter months and lowest during the summer months. Dry soil conditions during the fall and winter may cause soil pH values to be lower by 0.5 pH units or more. As a general recommendation, soil samples, regardless of collection method, should be collected near the same time of year and following the same crop in attempt to reduce variation in soil-test results caused by time and/or crop and soil management practices. Soil samples should always be collected before (not after) fertilizer, manure or biosolid application.

The second step in the soil-testing process is the chemical analysis of the soil conducted by a soil-testing laboratory. The University of Arkansas Soil Testing Laboratory uses the Mehlich-3 extractant to determine the availability index of nutrients, such as P, K, calcium (Ca) and magnesium (Mg). Some laboratories use different chemical methods to determine the availability of these nutrients. Therefore, soil nutrient concentrations from other labs may not apply to the recommendations that are listed in the following sections. Also, the units in which the nutrient concentration is expressed [e.g., pounds per acre (lb/acre) or parts per million (ppm or mg/kg)] are important for accurate interpretation of soil-test results. For example, 200 pounds of K per acre is the same as 100 ppm K. Soil-test units expressed as ppm can be converted to pounds per acre by multiplying ppm × 2 since units of pounds per acre usually assume that the soil sample represents a plow layer of soil that weighs 2 million pounds. The recommended 4-inch sample depth usually represents an acre-furrow slice that weighs from

900,000 pounds of soil per acre for clayey soils (bulk density ~1.0 g soil/cm^3) to 1,250,000 pounds of soil per acre for sandy loam soils (bulk density ~1.4 g soil/cm^3).

The third step in the soil-testing process is data interpretation and development of recommendations. Once the chemical analysis has been performed by the laboratory, someone must interpret what the numbers mean. Research defines the ranges of soil test values that are considered below optimum, optimum and above optimum for plant growth. Fertilizer recommendations are developed from field research, but may also incorporate different fertilization philosophies. The two most common philosophies that influence P and K fertilizer recommendations are "fertilize the crop" and "fertilize the soil." The idea of "fertilize the crop" is that fertilizer recommendations are based exclusively on crop response at a given soil-test level. The minimum rate of fertilizer that provides adequate growth for the current crop is recommended. If the nutrient availability index is considered sufficient for optimum productivity, no fertilizer is recommended. The second philosophy of "fertilize the soil" is that fertilizer recommendations are based on the needs of the current crop plus an additional amount recommended to 'build and maintain' soil fertility levels. Thus, the fertilize the soil philosophy is often based on a two-part equation that accounts for the amount of fertilizer needed to build the soil test value and the amount of fertilizer nutrient that will be removed by a certain yield. Concepts from both philosophies have been incorporated into research-based fertilizer recommendations for rice to account for factors such as field variability, rotation crop nutrient requirements and nutrient availability under flooded soil conditions.

Management Key

Soil-test results provide an estimate of nutrient availability to the plant and not the total amount of each nutrient that is found in the soil.

The final step in the soil-testing process is implementing the fertilizer recommendations and managing the soil-test information. Fertilizer recommendations represent either the average response to fertilization as determined by a large number of trials or a calculation that accounts for building soil-test values and nutrient removal by the harvested portion of the crop. Therefore, reasonable adjustments to fertilizer recommendations to accommodate specific farm situations and fertilization objectives are appropriate provided that state or federal nutrient management regulations are not broken. For example, one may apply higher fertilizer rates to build and maintain soil-test P and K values on land that is owned but apply lower fertilizer rates on land that is farmed on a short-term lease.

Monitoring field nutrient balances (e.g., nutrient additions minus removals) and field-, grid- or zone-specific, soil-test P, K and Zn values across time are important but often overlooked components of soil fertility management. Specifically, knowledge of crop yields and nutrient additions allows one to determine if soil nutrients are being depleted or accumulating across time. In row-crop production systems, large fluctuations (increases or decreases) in soil-test P and K values are unlikely to occur over a short time if nutrient inputs and removal are balanced. A history of soil-test information for individual fields plus the knowledge of nutrient balances allows one to determine if a particular year's soil test information is reasonably accurate (as compared to past years' results) or is being influenced by variability caused by time, space or field management; potential sample collection errors; laboratory analysis error; or nutrient imbalances. A spreadsheet (e.g., Microsoft Excel) can be used to track a field's soil test, yield and fertilization history. The information included in this chapter can be used to calculate nutrient removal by rice grain.

Sulfur

Rice does not normally require sulfur (S) fertilizer to produce high yields in Arkansas. Generally, adequate amounts of S are provided from soil organic matter, irrigation water and precipitation. The SO_4-S concentrations in irrigation water are highly variable in Arkansas and range from 2 to > 100 mg SO_4-S/liter (3.79 liters/gallon). On average, groundwater tends to contain more SO_4-S than surface water. About 4.5 pounds of SO_4-S is pumped onto fields for each acre-inch (27,154 gallons) of irrigation water that contains 20 mg SO_4-S/L. Thus, in most fields, the rice nutritional requirement for S will be supplied from irrigation water and the decomposition of organic matter. **Sulfur is most likely to be needed on sandy soils due to low organic matter con-**

tent and leaching of plant available SO_4-S. Sulfur may also be needed on soils that are continuously flooded for rice production and winter waterfowl habitat as plant-available S may be reduced to an unavailable form.

Early-season S deficiencies normally occur after establishing the permanent flood on permeable sandy soils. Deficiency symptoms appear similar to those of N deficiency. Sulfur-deficiency symptoms include initial chlorosis (yellowing) of the entire plant starting with the youngest leaves, reduced tillering, delayed maturity and stunted growth. While the chlorosis may start with the younger leaves, prolonged S deficiency eventually results in a uniform yellowing of young plants. Nitrogen-deficiency symptoms begin as a yellowing of the older leaves. Since visual symptoms may be difficult to distinguish from N deficiency, use plant tissue analysis for correct identification (Table 9-13). If S deficiency is verified, ammonium sulfate applied at 50 to 100 pounds per acre will supply sufficient amounts of S.

At maturity, rough rice grain usually contains 0.09% S, and rice straw may average about 0.11% S but will vary depending on S availability and fertilization practices. Based on an average yield of 200 bushels per acre and total aboveground biomass (grain and straw) of 20,000 pounds per acre, aboveground crop uptake and removal of S by harvested grain are approximately 20 and 8 pounds S per acre, respectively. The amount of S removed in the grain comprises approximately 40 percent of the total S taken up by the plant.

Sulfur deficiency may also occur late in the growing season despite no visible early-season S symptoms. Late-season S deficiency is more common than early-season S deficiency, and symptoms include yellowing of the flag leaf that starts at the leaf tip (Photo 9-4), flag leaf size is reduced and rice may be several inches shorter than rice in healthy field areas. Blackish-colored streaks between leaf veins usually develop if the problem is left uncorrected. Normally, the top two or three leaves exhibit these symptoms and lower leaves appear perfectly healthy. Fields showing these symptoms generally have been recently graded, sandy surface soil texture, sandy-textured subsoil (Photo 9-5), and/or may show symptoms each time the field is cropped to rice. Late-season application of ammonium sulfate tends to improve leaf color but may do little to increase yields if applied past the late-boot stage. Midseason application of ammonium sulfate (10 to 20 pounds SO_4-S per acre) may be needed on fields with a history of late-season S deficiency.

Table 9-13. **Guide for interpreting nutrient concentrations from plant tissue analysis†.**

Nutrient	Plant Part‡	Growth Stage	Nutrient Concentration Required for Adequate Growth††
Phosphorus (P)	Y-Leaf	Mid-tiller	0.14%-0.27%
Phosphorus (P)	Y-Leaf	Panicle Initiation	0.18%-0.29%
Potassium (K)	Y-Leaf	Mid-tiller	1.5%-2.7%
Potassium (K)	Y-Leaf	Panicle Initiation	1.2%-2.5%
Calcium (Ca)	Y-Leaf	Mid-tiller	0.16%-0.39%
Calcium (Ca)	Y-Leaf	Panicle Initiation	0.19%-0.39%
Magnesium (Mg)	Y-Leaf	Mid-tiller	0.12%-0.21%
Magnesium (Mg)	Y-Leaf	Panicle Initiation	0.16%-0.39%
Iron (Fe)	Y-Leaf	Mid-tiller	89-193 ppm
Iron (Fe)	Y-Leaf	Panicle Initiation	74-192 ppm
Manganese (Mn)	Y-Leaf	Mid-tiller	237-744 ppm
Manganese (Mn)	Y-Leaf	Panicle Initiation	252-792 ppm
Zinc (Zn)	Y-Leaf	Mid-tiller	22-161 ppm
Zinc (Zn)	Y-Leaf	Panicle Initiation	33-160 ppm
Sulfur (S)	WS	Mid-tiller	0.17%
Sulfur (S)	WS	Panicle Initiation	0.15%
Sulfur (S)	Flag leaf‡‡	Late Boot to Anthesis	0.15%

† Unless noted otherwise the source of the nutrient-sufficiency values is Reuter, D.J. and J.B. Robinson, 1986. Temperate and subtropical crops. p. 38-99. In D.J. Reuter and J.B. Robinson (ed.) *Plant Analysis: An Interpretation Manual.* Inkata Press, Melbourne.

‡ Plant part – Y-leaf is the youngest fully emerged (uppermost) leaf blade on the rice plant; WS – whole shoot – entire aboveground portion of plant.

†† Nutrient concentrations required for adequate growth – the range of concentrations listed for the specific plant parts does not increase nor decrease plant growth or production. Concentrations lower than those listed may limit production and result in visual nutrient deficiency symptoms. ppm = mg\kg.

‡‡ Source: Slaton et al., 2001. p. 388-394. *Ark. Rice Res. Studies 2000.* Ark. Ag. Exp. Sta. Res. Ser. 485.

Management Key

Use ammonium sulfate as part of midseason N needs on fields with a history of late-season S deficiency.

Photo 9-4. Symptoms (on upper leaves) due to late season sulfur deficiency.

Photo 9-5. Sulfur deficiency occurring in sandy area of field.

Applications of elemental S have proven to be effective at reducing soil pH and improving rice productivity on calcareous soils with a history of high pH-related problems (Table 9-14). Application of 500 pounds S^0 per acre (90 percent S) has been required to reduce soil pH enough to affect rice grain yields. Also, different elemental S sources require different lengths of time to effectively lower soil pH (Table 9-15). Some elemental S materials break down in a few weeks while others may require months or years to effectively reduce soil pH to a desirable level. Increased rice growth and yield from elemental S application is attributed to the increased availability of other essential nutrients (e.g., P and Zn) from soil acidification and not from increased S nutrition. Application of ammonium sulfate will also reduce soil pH when applied at very high rates; however, elemental S is over twice as acidic as ammonium sulfate. Elemental S should be applied in the fall or winter to "problem" high pH areas to allow the product to be oxidized (e.g., broken down) and lower pH before seeding. Elemental S is an expensive soil amendment and will lower soil pH only temporarily if groundwater high in Ca and Mg bicarbonates is used. Lowering soil pH with elemental S can be expensive and should be done only after consultation with an Extension rice or soils specialist.

Table 9-14. Rice grain yield, soil pH and electrical conductivity as influenced by an elemental sulfur (S^0) product at two locations†.

S^0 Rate	Grain Yield	Soil pH	Soil EC
lbs/A	bu/A		µS/cm
0	120	7.5	338
223	123	7.4	347
446	130	7.0	490
670	134	6.8	609
893	141	6.8	611
1785	142	6.5	775

† Soil pH and EC measured in a 1:2 soil weight:water volume ratio 34 d after S^0 application.

Source: Slaton et al., 1998. p. 322-325. *B.R. Wells Rice Res. Studies 1998*. Ark. Ag. Exp. Sta. Res. Ser. 460.

Table 9-15. Influence of two elemental sulfur products on rice grain yields and soil pH 34 days after application.

	Grain Yield		Soil pH†	
S^0 Rate	Tiger 90	Wettable S	Tiger 90	Wettable S
lbs/A	bu/A		bu/A	
0	97	97	7.6	7.6
223	109	111	7.4	7.1
446	103	136	7.2	6.6
670	119	127	7.3	6.3
893	123	119	7.4	6.0
1,785	111	141	7.2	5.1

† Soil pH 1 year after 1785 lb S/A application was 6.6 and 5.5 for Tiger 90 and Wettable S, respectively.

Source: Slaton et al., 1998. p. 326-329. *B.R. Wells Rice Res. Studies 1998*. Ark. Ag. Exp. Sta. Res. Ser. 460.

Phosphorus and Potassium

Rice response to P and K fertilization is usually not as dramatic as that from N. Fertilization with P and K, when needed, may be accomplished in several ways. If rice is grown in a rotation of two years of soybean followed by one year of rice, addition of P and K, according to soil-test recommendations, to the soybean crop may provide adequate residual P and K for production of near maximal rice yields. If rice is grown continuously or in a 1:1 rotation with soybean, P and/or K fertilizer may need to be added directly to the rice crop to maintain productivity of the soil. Routine soil testing is the best available criteria to establish the necessity of applying P and K to rice and rotational crops.

Phosphorus

Phosphorus fertilizer recommendations for rice are based on soil testing for available P and soil pH (Table 9-16). Phosphorus availability to rice is optimum when the pH is below 6.5. For upland crops, P availability is usually optimal when the soil pH is between 6.0 and 6.5. In acid soils (pH < 6.0), the P is associated ("tied up" or "fixed") with iron (Fe) and aluminum (Al) compounds that are slowly available to most plants. When the soil pH is greater than 6.5, the P is primarily associated with Ca and Mg. Not all Ca and Mg phosphate compounds are slowly available to plants since their availability declines as pH increases. In acid soils, P availability increases following establishment of the permanent flood due to the chemical changes (e.g., reduction) that occur to the Fe phosphate. Thus, more P is usually available for rice uptake and not limited following the flood in soils with a pH < 6.5 than is measured with routine soil-test methods. In contrast, the availability of Ca phosphates tends to be low and may remain low for several weeks after flood establishment in higher pH soils (pH > 6.5). The Mehlich-3 soil test alone does not adequately predict P availability to rice. To improve the soil-test based predictions regarding the soil P availability to rice, both Mehlich-3 extractable P and soil pH are used in making P fertilizer recommendations (Table 9-16).

Table 9-16. Phosphorus fertilizer recommendations for flood-irrigated rice based on soil-test P (Mehlich-3) and soil pH (water pH measured in 1:2 soil:water mixture).

Soil-Test Level	Soil-Test P Range	Soil pH < 6.5	Soil pH ≥ 6.5
		lbs P_2O_5/A	
Very Low	< 9 ppm	50	70
Low	9-16 ppm	40	60
Medium	17-25 ppm	30	50
Optimum	26-50 ppm	0	0
Above Optimum	> 50 ppm	0	0

Soil-test methods currently used by both university and private laboratories are limited in their ability to predict rice response to P fertilization. All soil-P extractants or soil-test methods were developed for crops grown under upland (not flooded) conditions. Use of soil pH and soil-test P more accurately identifies soils that require P fertilization to produce maximal plant growth and yield in Arkansas. Soil pH is not static and can vary by as much as 1.0 pH unit during the year, depending on sample time, environmental conditions and other factors. Recommended P fertilizer rates based on soil-test P (Mehlich 3) and soil pH are listed in Table 9-16. Application of P fertilizer to undisturbed (i.e., nongraded) acid soils that test low in P has failed to show significant yield increases and, in some cases, has increased lodging (especially on lodging-sensitive cultivars), caused rank vegetative growth and/or decreased yield. The yield results in Tables 9-17 and 9-18 highlight the need for caution when applying P to lodging-prone cultivars or hybrids, especially on soils with a pH < 6.5.

Table 9-17. The effect of P fertilizer rate on grain yield and lodging of CL151, a high-yielding, lodging-prone variety.

P Fertilizer Rate	PTRS-2011† Lodging	PTRS-2011† Grain Yield	PTRS-2012‡ Lodging	PTRS-2012‡ Grain Yield
lbs P_2O_5/A	% lodged	bu/A	% lodged	bu/A
0	20	187	1	194
40-45	42	179	15	182
80-90	59	181	9	177
120	--	--	29	186

† 2011 Trial info: Calloway silt loam with an average soil-test P of 6 ppm and soil pH was 6.5 [Slaton et al., (2011) unpublished].

‡ 2012 Trial info: Calloway silt loam with an average soil-test P of 18 ppm and soil pH was 7.4 [Slaton et al., (2012) unpublished].

Table 9-18. Influence of P fertilizer application on whole plant P tissue concentration and grain yield at two locations during 1995†.

P Fertilizer Rate	Cross County pH = 8.0 Tissue P	Cross County pH = 8.0 Grain Yield	Poinsett County pH = 5.8 Tissue P	Poinsett County pH = 5.8 Grain Yield
lbs P_2O_5/A	%	bu/A	%	bu/A
0	0.10	64	0.32	155
40	0.10	119	0.36	143

† Mehlich-3 soil-test P was < 10 ppm for both locations.

Source: Wilson et al., 1996. p. 196-200. *Ark. Rice Res. Studies 1995*. Ark. Ag. Exp. Sta. Res. Ser. 453.

Management Key

Silt loam soils with a soil pH > 6.5 and very low soil-test P levels are most likely to result in yield responses to P fertilizer.

Many growers are concerned about very low soil-test P levels and are interested in raising these to higher values with extra P fertilizer application. Research has found that soil-test P usually declines (from previous soil-test times) when soil samples are taken following rice in the crop rotation, even when extra P fertilizer was applied. This decrease is usually representative of P availability to upland crops like soybean and is due to changes in soil P compounds under alternating aerobic-anaerobic soil conditions. In general, soil-test P slowly increases with time after rice fields are drained for harvest or when soil samples are collected after soybean is grown in the rotation the following year. The application of higher than recommended P fertilizer rates to increase soil-test P levels may be difficult and uneconomical when rice is grown in the rotation. The best strategy to ensure adequate P nutrition to crops is to apply the recommended rate of P fertilizer directly to each crop.

In addition to recommendations based on soil-test results, P fertilizer is also recommended when the soil has been recently precision graded.

For precision-graded soils, 40 pounds P_2O_5 per acre is recommended, unless the soil test calls for a higher amount. Phosphorus content tends to decline with soil depth and is usually needed on fields that have been precision graded. This is in addition to the recommended rate of poultry litter. Blanket P fertilizer applications to precision-leveled soils should be done for three to four years. If soil productivity appears to be restored to normal, applications of poultry litter and P may be discontinued or limited to "problem areas" within the field. Subsequent P applications should be based on soil-test results.

Regardless of the situation where P fertilizer is recommended, several fertilizer sources and application timing options are available to growers. Triple superphosphate (TSP, 0-46-0) is commonly used as the preplant fertilizer source. Diammonium phosphate (DAP, 18-46-0) is often competitive with TSP in price and is frequently used. Mono-ammonium phosphate (MAP, 11-52-0) and MicroEssentials (MESZ, 10-40-0-10S-1Zn) are other commercially available P fertilizers that may be available in Arkansas and suitable for application to rice. Research comparing multiple P sources has consistently shown no difference in rice grain yield or P uptake among P fertilizer sources. If other pre-plant fertilizers are not required, P fertilizer can be blended and applied with N applications made before flooding. Preflood P applications are as effective as preplant P applications and may offer a savings in application costs if applied aerially with preflood urea (Table 9-19). DAP is commonly used in this situation since it also contains some ammonium-N. On soils that have a history of P deficiency or are highly responsive to P fertilization, preflood application is sometimes better than preplant application.

Table 9-19. Influence of P fertilizer application timing on rice grain yields at four locations.

Time of Application	Davis Farm 1997	Davis Farm 1998	Wimpy Farm 1997	Wimpy Farm 1998
	bu/A			
Control	126	152	143	138
Pre-emerge	152	163	150	134
Preflood	143	170	156	139
Postflood (7 days)	157	187	156	136
Panicle Differentiation	131	163	147	133
Soil-test P (ppm)	10	17	28	20
Soil pH	7.6	6.8	8.0	7.7

Source: Wilson et al., 1999. p. 310-316. *Ark. Rice Res. Studies 1998*. Ark. Ag. Exp. Sta. Res. Ser. 468.

Recent research has shown no difference in rice P uptake or grain yield between fall- and spring-applied P fertilizer. However, on occasion, we have observed P deficiency of rice in fields that have received fall or spring P fertilization. Thus, there is lower probability of the P fertilizer being fixed into an unavailable form and seedling rice becoming P deficient when the P fertilizer is applied as close to rice planting (preplant or preflood) as possible on responsive soils. In fields, where P deficiency is not expected and P fertilizer is applied to maintain the existing soil-test P level at a Medium or Optimum level, P fertilizer may be applied in the fall or early spring. Situations where we do not recommend fall P fertilization include fields/soils that have low or very low soil-test P levels, will be flooded during the winter for waterfowl habitat and where crop P deficiency has been recently observed.

Management Key

If a high rate (50 to 70 pounds P_2O_5 per acre) of P is recommended, a split application may be useful on highly responsive soils (one-half to two-thirds applied preplant followed by one-third to one-half applied before flooding).

When seedling rice is P deficient, application of P fertilizer as late as panicle differentiation may improve growth and increase yield (Table 9-19). **However, the yield increase from P fertilizer applied at midseason is usually less than that from P fertilizer applied earlier in the growing season.**

Phosphorus deficiency symptoms on seedling rice may include severe stunting; small, very erect and dark green leaves; small diameter stems; lack of tillering and delayed plant development (Photo 9-6). Leaf chlorosis and bronzing may also be present on P-deficient seedlings. These symptoms may be followed by rapid deterioration of the older leaves, especially after the flood is applied. The symptoms have most commonly been observed 7 to 14 days after permanent flooding (mid-tillering). Symptoms may resemble those of zinc (Zn) deficiency and, like Zn deficiency, have been observed primarily on graded fields or alkaline (high pH) silt loam soils. Because of the similarity with Zn deficiency symptoms, plant tissue analysis is the best means for correctly diagnosing which nutrient is causing the poor rice growth (Table 9-13). Arkansas research suggests that at the mid-tillering stage (about two weeks after flooding) rice seedlings (whole aboveground plant) with P concentrations > 0.20 percent P are P sufficient, 0.15 to 0.20 percent P are low, and < 0.15 percent are likely P deficient.

Photo 9-6. Phosphorus deficiency of rice. Notice dark green streak with stunted plants and reduced tillering.

Rough rice grain has an average P concentration of 0.29% P (±0.02%) resulting in removal of 0.30 pound P_2O_5 per bushel of rough rice. An average rice yield of 200 bushels per acre will remove approximately 27 pounds of elemental P per acre, which is equivalent to about 61 pounds P_2O_5 per acre. The amount of P removed in the grain usually comprises 60 to 70 percent of the total aboveground P uptake. A mature rice crop, including grain and straw (all above-ground biomass), may weigh 20,000 pounds per acre (dry weight) and contain on average about 100 pounds P_2O_5 per acre. The rice straw typically contains 0.159% P (±0.06%) with a total content of about 40 pounds P_2O_5 per acre.

Potassium

Potassium fertilizer is recommended on soils that test < 131 ppm K (< 262 pounds K per acre, Table 9-20). Potassium fertilizer recommendations are based solely on soil-test K. The salts added by recommended amounts of K fertilizer are small compared to the amount of salts already in the soil or that are added with irrigation water. In K-deficient soils, rice yields are potentially more limited by inadequate K than by the potential salinity injury resulting from K fertilization. Application of P with K fertilizer may reduce salinity damage aggravated by K fertilizer application. Application of K fertilizer in the fall or several months before seeding also may help reduce the amount of salts in the root zone.

Management Key

Soils that test ≤ 60 ppm K (≤ 120 pounds K per acre) are very susceptible to K deficiency and receive a higher recommended K fertilizer rate to build soil-test K.

Rice grown on soils with a 'Medium' soil-test K level (91-130 ppm) usually will receive only nominal benefit from K fertilization (Table 9-20). However, K is recommended to account for spatial variability in soil-test K within fields, temporal variability in soil test K and to help maintain sufficient soil K levels for future crops. Silt and sandy loam soils in Arkansas have a low buffering capacity (i.e., ability to maintain soil-test K levels without frequent fertilization), and soil-test K can decline rapidly if K fertilizer is omitted for several consecutive crops. Potassium fertilizer should be applied before seeding or before flooding because plant uptake of K is most rapid during the first three or four weeks after flooding. Soils that have 'Very Low' soil-test K and are very sandy may benefit from split applications of K (i.e., preplant or preflood followed by a second application near the beginning internode elongation stage).

Potassium fertilizer is generally recommended when rice shows K deficiency symptoms during the season. Research has shown excellent yield response and prevention of yield loss from K fertilizer applied to rice with mild to moderate K deficiency at midseason (e.g., panicle differentiation) and late boot stage (Table 9-21). However, K fertilizer should be applied as soon as the K deficiency is positively identified since the magnitude of response tends to decline as rice approaches heading. Potassium fertilizer application after panicle exsertion begins has not, to our knowledge, been evaluated, but we speculate that the yield benefit of K fertilization after anthesis would be nominal and is therefore not recommended. Potassium fertilizer is very water soluble and when applied into the flood water or on the soil surface immediately before flooding will result in a significant portion of the applied K being dissolved in the floodwater. Thus, for postflood K applications, the K fertilizer should be applied and the floodwater kept static to prevent K movement within the field (areas with a high elevation to areas with lower elevation) for five to seven days. The recommended K fertilizer application rate for aerial application onto K-deficient rice is 60 pounds K_2O per acre.

Table 9-20. **Potassium fertilizer recommendations based on soil-test K (Mehlich-3) in the top four inches of soil.**

Soil-Test Level	Soil-Test K Range	K Fertilizer Rate
		lbs K_2O/A
Very Low	≤ 60 ppm	120
Low	61-90 ppm	90
Medium	91-130 ppm	60
Optimum	131-175 ppm	0
Above Optimum	≥ 175 ppm	0

Table 9-21. **Rice yield response to K fertilizer (average of 60 and 120 lb K_2O/acre) applied at the 5-leaf stage, beginning internode elongation (BIE), and late-boot stage before panicle exsertion.**

K Application Stage	Dry Matter	Grain Yield	Yield Difference
	lbs/A	bu/A	bu/A
No K applied	10,368	154	--
5-leaf or preflood	11,263	171	17
BIE or midseason	11,041	170	16
Late boot	10,679	164	10

Source: Maschmann et al. (2010; *Agronomy Journal* V102:163-170).

Potassium deficiency symptoms seldom appear on rice before the onset of reproductive growth (i.e., internode elongation). During vegetative growth, rice grown on K-deficient soils usually has a normal color with little or no reduction in tillering but may lack vigorous growth, making rice slightly shorter with some mild bronzing on the lower, older leaves. These symptoms are difficult to recognize and attribute to K deficiency in production fields. During reproductive growth, K deficiency symptoms include stunted plants (i.e., reduced height), droopy and dark green upper leaves (seldom seen in Arkansas), yellowing of the interveinal areas of the lower leaves starting from the leaf tip, leaf tips that eventually die and turn brown and development of brown spots on all leaves (Photos 9-7 and 9-8). The symptoms will often appear in and along the barrow ditches first.

Photo 9-7. **Potassium-deficient leaf (top) compared to healthy leaf (bottom). Note severe brown spot and yellow/brown leaf margins of K-deficient leaf.**

Photo 9-8. **Potassium-deficient rice at heading. Note brown spot on leaves and panicles.**

The deficiency symptoms generally start to appear near midseason and may first be noticed when the plants do not "green up" after midseason N is applied.
As the deficiency progresses, plants may develop severe disease infestation due to the plants' reduced ability to resist infection. Diseases that are normally insignificant, such as brown leaf spot and stem rot, may become severe in addition to diseases such as rice blast. While these diseases are typically more severe in K-deficient areas, they are not, by themselves, indications of K deficiency. Field observation also suggests that the development of severe brown spot is somewhat cultivar dependent. For example, brown spot was a more common symptom of K deficiency of cultivars grown in the 1980s and 1990s than on the currently grown varieties and hybrids. Reasons for this are not clear but may include, among other factors, plant genetics as it - pertains to disease resistance and changes in the efficacy of fungicides applied to rice.

Potassium is highly mobile in the plant, and deficiency symptoms occur first and tend to be most severe on the oldest (lower) leaves. As such, K deficiency symptoms will be worse on the lowest, oldest leaves. When the tips of the upper rice leaves turn yellow and then brown, it suggests that K deficiency is very severe and can be confirmed by examination of more severe symptoms on the older leaves or, in the absence of obvious K-deficiency symptoms on the older leaves, that another problem exists. The symptoms of yellowing and/or browning of leaf tips are not exclusively diagnostic of K deficiency but may be caused by a host of other factors and are often more pronounced on some cultivars and in some years. Application of an excessive N fertilizer rate often causes these symptoms. Plant tissue analysis is an effective means of determining whether K deficiency is the problem. Potassium-deficient plants often accumulate sodium (Na). Whole aboveground rice plant K concentrations > 2.00 percent at midseason (panicle initiation to differentiation stage) and > 1.3 percent at late boot are considered sufficient for the production of high yields. Healthy rice with sufficient K may have whole plant Na concentrations of 1,000 to 2,000 ppm and K-deficient plants usually have much higher Na concentrations of 3,000 to 10,000 ppm at the boot stage.

Potassium deficiency may also result in a situation known as **"hidden hunger."** This is when the plant does not have sufficient amounts of K to make optimum yields but deficiency symptoms are mild or not present. Hidden hunger has been observed in research areas where fertilized and nonfertilized plots look similar but yield differences of 20 to 50 bushels/acre have been measured (Table 9-22). For example, at the Lake Hogue location, severe stem rot was observed during late boot, but no leaf K deficiency symptoms were visible during the growing season. The average soil-test K at this site was considered Medium and K fertilizer would have been recommended, but the large yield response to K fertilization was not expected (Table 9-20). Therefore, it is imperative that fields be soil sampled and fertilized appropriately. Very Low or Low soil-test K levels can result in large yield losses with the plants providing few visible symptoms.

Management Key

Proper soil sampling and K fertilization is critical to avoid major yield losses from K deficiency.

Table 9-22. **Influence of potassium rate on rice grain yield at four locations during 2005.**

K Fertilizer Rate	Grain Yield Poinsett	Cross	Lake Hogue	Pine Tree
lbs K_2O/A	bu/A			
0	107	179	133	189
40	150	196	159	193
80	152	195	160	196
120	158	195	163	202
160	157	183	176	197
LSD 0.10	19	10	13	n.s.
Soil Test K (ppm)	64	71	94	99

Source: Slaton et al., 2006. p. 333-340. *B.R. Wells Rice Res. Studies 2005*. Ark. Agr. Exp. Sta. Res. Ser. 540.

The K concentration in rough rice averages 0.28% K (±0.025%) resulting in removal of about 0.15 pounds K_2O per bushel. An average rice yield of 200 bushels per acre will remove approximately 30 pounds K_2O per acre. At maturity, the straw of a well-fertilized rice crop has an average K concentration of 1.40% K (±0.34%) and contains the equivalent of about 180 pounds K_2O per acre. Although in excess of 200 pounds K_2O per acre is contained in the rice grain and straw at maturity, only 10 to 20 percent of the K taken up is removed in the harvested grain. University of Arkansas K fertilizer recommendations are based on soil-test K and should help build soil K levels when soil-test K is below optimum because rice removes a low amount of the total K that is taken up. It should be remembered that immediately after harvest of any crop the K not removed by grain may still be in the stubble. Thus, soil-test K should increase as K leaches from stubble back into the soil with time.

Poultry Litter as a Fertilizer Source on Nongraded Fields

Poultry litter contains appreciable amounts of many nutrients (Table 9-23), including N, P and K, and may be used as an alternative to inorganic P and K fertilizers. The price of P and K fertilizers compared with the price and availability of poultry litter should be used to evaluate the economics/feasibility of using poultry litter or other manures and biosolids as a P and K source. When poultry litter is used as a P and K fertilizer, representative samples should be submitted to a qualified lab for analysis because poultry litter is not a homogeneous or consistent product; differences exist among houses, companies and/or poultry type. On average, one ton of poultry litter contains 65 to 66 pounds P_2O_5 and 46 to 59 pounds K_2O, making it equivalent to 144 pounds of triple superphosphate (0-46-0) and 77 to 98 pounds of muriate of potash (0-0-60). The nutrient content of the litter usually decreases as moisture content increases since litter is analyzed on an 'as is' or moist basis. Research shows that the P and K in poultry litter are plant available and should be applied at rates that supply the recommended P_2O_5 and K_2O rates. Fresh and pelleted forms of poultry litter behave similarly with regards to the plant availability of N, P and K.

Preplant incorporated poultry litter will also contribute some N to the current year's rice crop. Rice and weed growth before flooding is usually quite vigorous on silt loam soils receiving poultry litter. **However, research shows that only about 25 percent of the total N in poultry litter is recovered by rice grown in the delayed-flood system.** Thus, when poultry litter is applied preplant to delayed-flood rice, the preflood-N rate should only be reduced by 25 percent of the total N content of the poultry litter. For example, if 1.5 tons per acre of poultry litter that is 4.0 percent N is incorporated before planting, then 120 pounds of total N per acre has been applied in the poultry litter. To account for the poultry litter N, the preflood urea-N rate would be reduced by 30 pounds N per acre (120 pounds PL-N × 0.25). Much of the N in poultry litter applied preplant to delayed-flood rice becomes plant available (mineralized) within three or four weeks following application and can be rapidly converted to nitrate and eventually lost via denitrification when fields are flush irrigated or flooded. Applying poultry

Table 9-23. **Mean and standard deviation of selected chemical and physical properties of moist broiler, hen and turkey litter samples analyzed by the University of Arkansas Fayetteville Agricultural Diagnostic Laboratory from 2005-2009.**

Property	Broiler Litter		Hen Manure		Turkey Litter	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Observations	514	--	208	--	38	--
Moisture, %	30.2	8.9	39.7	15.9	29.5	7.9
pH	8.3	0.4	8.7	0.5	8.2	0.5
EC, µmhos cm^{-1}	11,400	2,410	7,734	2,486	8,545	1,769
Total C, %	25.5	3.9	19.4	6.78	26.6	3.3
Total N, %	3.08	0.51	2.06	0.89	3.53	0.76
C:N ratio	8.34	1.11	10.2	4.6	7.7	1.4
Organic N, %	85.2	6.1	82.7	11.4	85.0	5.9
NH_4-N, mg kg^{-1}	3,392	1,517	2,568	1,356	4,956	2,099
NO_3-N, mg kg^{-1}	420	800	365	783	227	319
Total P_2O_5, %	3.28	0.66	3.32	0.94	3.30	0.60
Total K_2O, %	2.96	0.50	2.29	0.55	2.66	0.36
Total Ca, %	2.38	0.71	5.66	1.68	2.40	0.44

litter to the soil surface with no incorporation or far in advance of planting may reduce the amount of N available to the rice crop. Greater amounts of the N present in poultry litter may be recovered by rice produced in water-seeded systems, but because water-seeding is not a common practice in Arkansas, no research has been conducted in this production system.

Growers interested in using poultry litter as a P and K source for rice should have the litter analyzed for its N, P and K content. The type of poultry produced, bedding material, composting and the frequency of house cleanout (number of flocks) influence the nutrient content of poultry litter. Several subsamples of poultry litter should be collected from the source (i.e., house, truck or stack) and divided into at least two or three composite samples. Poultry litter from different stacks or poultry houses requires separate composite samples. Composite samples of manure should be placed into quart-size, sealable bags and submitted to a reputable laboratory for analysis of total nutrient content. Samples can be sent to the University of Arkansas Division of Agriculture Fayetteville Agriculture Diagnostic Laboratory (479-575-3911) for analysis through the county Extension office. A small fee is charged for manure analysis.

Management Key

Poultry litter is an equivalent alternative to inorganic P and K fertilizers applied to rice, but only about 25 percent of the total N in poultry litter is equivalent to preflood urea.

The use of poultry litter as a nutrient source requires some precautionary measures. Poultry litter should not be applied at rates > 2 tons per acre because it contains appreciable amounts of soluble salts that may reduce rice stand density. Likewise, poultry litter contains relatively high amounts of P which can cause soil-test P to increase rapidly when applied repeatedly at high rates. Very high rates of P fertilization may reduce rice yields, increase lodging and induce deficiencies of other nutrients. For soils testing Very Low or Low in K, inorganic K fertilizer may still be required unless litter is applied at rates > 1 ton per acre. Poultry litter also has some liming properties and, when used continuously at moderate to high rates, may help maintain or perhaps increase soil pH.

Poultry litter also contains many micronutrients; however, the concentration of micronutrients (e.g., Zn) in litter is usually quite low, making poultry litter a poor source of micronutrients on deficient soils. For example, one ton of poultry litter usually contains < 0.1 pound B, 0.5 pound Zn, 0.7 pound Cu and 8 to 10 pounds of S. Repeated use of poultry litter or other animal manures may eventually build soil-test micronutrient levels.

Liming

Liming a soil is generally for the benefit of the other crops in the rotation because rice grows well in moderately acidic soil. However, rice yields may also benefit from lime when soil pH is near 5.0 or lower. Rice response to liming is often negative due to uneven lime distribution, excessive application rate and/or application to field areas that do not require lime. Deficiencies of P and Zn may occur in rice fields, especially near well water inlets, that have received recent lime applications. Thus, after liming, P and Zn fertilization of the next rice crop should be considered. Soil samples should be collected the year following lime application in the winter months before rice is grown to monitor changes in soil-test results and obtain updated fertilizer recommendations.

If liming is necessary to optimize the growth and yield of other crops in the rotation, the lime should be applied immediately after the rice crop and prior to the production of the rotation crop, not immediately ahead of the rice crop (Table 9-24). Use of grid soil sampling and variable rate application equipment are highly recommended for lime application to fields with rice in the rotation. If grid soil samples are not

Table 9-24. Lime rates by soil texture for soils that have rice in the rotation†.

Soil Texture	Soil pH			
	< 5.0	5.0-5.3‡	5.4-5.7††	5.8-6.2
	lbs ag lime/A			
Sandy loam	2000	2000	0	0
Silt loam	3000	2000	0	0
Clay loam	4000	3000	0	0
Clay	5000	4000	0	0

† Lime upper half of field only when well water calcium concentration is < 3 meq Ca/L and pH of water inlet area < 5.5.
‡ Apply lime to crops grown in rotation with rice in this pH range.
†† Consult soil-test recommendations to determine the lime recommendations for specific crops grown in rotation with rice.

used, take extreme care in soil sampling, especially if the irrigation water source is a well, so that a correct lime recommendation can be made in the appropriate areas of the field.

Follow correct soil sampling procedures so that soil-test results for lime and other nutrient recommendations are representative. If grid samples are not being collected, collect composite soil samples from the area near the water inlet, the center and the bottom portions of the field, as well as areas that differ in soil series or texture within these locations. **One composite soil sample should not represent more than 20 acres.** Composite samples near water inlets should represent no more than 5 acres. To determine the lime contribution of the irrigation source, the irrigation water should be sampled. Water sampling kits may be obtained at the county Extension office. Analysis of irrigation water is performed for a fee by the Arkansas Water Resources Center, Biomass Building Room 106, 2435 North Hatch Avenue, Fayetteville, AR 72704 (479-575-7317).

Zinc

Zinc deficiency normally occurs on silt and sandy loam soils or on precision-graded fields. The availability of native soil Zn is reduced when soil pH is increased either from the use of calcareous irrigation water, over-liming and/or exposure of Zn-deficient subsoils by land leveling. Correction of Zn deficiency requires reduction of soil pH and/or the addition of a suitable Zn source. Zinc deficiency is not commonly observed on clay soils in Arkansas, but it has been documented on a few fields that have been precision graded and/or have high pH.

Zinc deficiency, P deficiency and salinity injury symptoms are easily and often confused. Zinc deficiency symptoms are usually observed after flushing or flooding, whereas problems from salinity may occur prior to flushing or flooding under dry soil conditions or following irrigation if the irrigation water contains excessive salt. Salinity injury, P deficiency and Zn deficiency can all be present in the same field. Phosphorus deficiency is also similar to Zn deficiency in that the symptoms typically occur after flooding. However, leaves are usually more erect and leaf chlorosis (yellowing) at the leaf base (e.g., leaf blade above the collar) is usually not present with P deficiency. Also, Zn deficiency appears much sooner after the flood is established, usually within a few days, whereas it generally takes a week or two after flooding to recognize P deficiency. Plant tissue analysis is the most effective means of correctly distinguishing which nutrient is the cause of the unhealthy rice (Tables 9-13 and 9-25).

Table 9-25. **Interpretation of whole plant (seedling) tissue analysis for salt (salinity), Zn and P concentration.**

Analysis	Tissue Concentration†		
	Normal	Possible	Probable
	mg/kg or ppm		
Zinc, ppm	> 20	15-20	< 15
Phosphorus, %	> 0.20%	0.15-0.20%	< 0.15%
Chloride, ppm	< 10,000	10,000-12,000	> 12,000
Nitrate, ppm	< 1,600	1,600-2,400	> 2,400

† **Normal** refers to healthy seedling rice tissue concentrations. **Possible** means that injury could be due to concentrations in this range. **Probable** means that injury was very likely due to concentrations in this range.

Zinc deficiency symptoms usually are not observed until shortly after flooding, when they have become severe enough that the flood must be removed in order to salvage the rice. However, rice seedlings are often Zn deficient before the flood is applied. Prior to flooding, the symptoms are usually subtle and difficult to recognize. Seedling rice can obtain sufficient nutrients from the seed for about 10 days after emergence. Therefore, Zn deficiency symptoms may not appear on rice seedlings until the 2- or 3-leaf stage. The Zn deficiency symptoms, whether subtle if observed before flooding or severe if observed after flooding, include:

1. Basal leaf chlorosis – the portion of the leaf nearest the stem becomes light green while the leaf tip remains a darker green. Usually begins in the youngest leaf (Photo 9-9).
2. Bronzing – consists of brown to red splotches starting on the surfaces of the oldest leaves (Photo 9-10). Bronzed leaf tissue may eventually turn brown. The midrib of the lower leaves may be pale green or yellow and be surrounded by the bronzed leaf tissue.
3. Short plants – stacking of leaf sheaths or joints makes the rice appear stunted and shorter than normal.

Photo 9-9. **Basal chlorosis of bottom leaf and midrib of Zn-deficient plant.**

Photo 9-10. **Mottled discoloration due to chlorosis and bronzing of lower rice leaves caused by prolonged Zn deficiency. Note the stacked leaf collars on the plants to the left.**

4. Flaccid plants or floating leaves – the leaves or plants may lose turgidity and float on the water surface if the rice is flooded or being flushed. Flushing seedling rice can aggravate Zn deficiency, cause the visual symptoms mentioned to become more noticeable and enable visual diagnosis before flooding to avoid a salvage situation. So pay close attention to the young rice when flushing. The loss of leaf turgidity is a difficult symptom to evaluate since deep water may also cause seedlings to elongate and lay on the water. Zinc deficiency symptoms are often noted within 72 hours after flooding and are aggravated by deep and cold water. Environmental factors such as cool temperatures or damage to the rice root system by insects or herbicides may increase the severity of Zn deficiency. Likewise, high P fertilizer rates may aggravate a Zn deficiency. Field history and soil pH combined with soil-test Zn are the two best methods for determining if Zn fertilizer is needed. Zinc deficiency should be documented by plant (Table 9-25) and soil analysis.

Zinc fertilizer recommendations are based on soil texture (silt and sandy loam soils), soil-test Zn (Mehlich-3 Zn ≤ 4.0 ppm) and soil pH (> 6.0, Table 9-26). When all three of these criteria are met, application of Zn fertilizer is recommended. The native soil-test Zn (Mehlich-3 Zn) for most topsoil in Arkansas is generally < 2.5 ppm. Zinc deficiency occurs primarily on soils with moderate to high pH (> 6.0) and low soil-test Zn (< 2.0 ppm). Soil-test Zn (Mehlich-3 Zn) levels greater than 4.0 ppm suggest a history of Zn fertilizer use, and a crop response to Zn fertilization is not likely. If soil-test Zn is high and rice continues to get sick after flooding, another nutrient may be deficient or the field may have a large variation in soil-test Zn within the field.

Table 9-26. **Soil-test Zn and soil pH based Zn fertilization recommendations for rice.**

		Soil-Test Zn Level and Concentration			
		Very Low	Low	Medium	Optimum
Soil Texture	Soil pH	≤1.5 ppm	1.6-2.5 ppm	2.6-4.0 ppm	≥ 4.1 ppm
		lbs Zn/A			
Sandy Loam and Silt Loam	> 6.0	10	10	1 to 10	0
	≤ 6.0	5 to 10†	0	0	0
Clay Loam and Clay	> 6.0	10	0	0	0
	≤ 6.0	10†	0	0	0

† Recommended for general maintenance of soil-test Zn.

When soil pH is ≤ 6.0 and soil-test Zn is Very Low (≤ 1.5 ppm), Zn fertilization is recommended as a precautionary measure on loamy and clayey-textured soils (Table 9-26). Application of a granular Zn source at 5 to10 pounds Zn per acre for loamy soils or 10 pounds Zn per acre for clayey soils is recommended to increase soil-test Zn, especially if well water is the irrigation source.

Zinc deficiency may be corrected by either acidifying the soil or applying a suitable Zn fertilizer source at the proper rate and timing. Acidification of the soil requires the addition of elemental S at 500 to 1,000 pounds per acre (Table 9-14) but is not likely economical. Repeated broadcast application of lower amounts of elemental S may not be sufficient to lower the pH and benefit the rice crop (Tables 9-14 and 9-15) unless the elemental S is applied in bands.

Zinc fertilizer may be applied on the soil before planting, as a seed treatment, on the soil surface after planting or as a foliar application to seedling rice. The Zn source determines the proper rate and application timing (Tables 9-27 and 9-28). Studies of granular Zn materials show that the degree to which granular Zn fertilizers dissolve in water is an indication of the relative effectiveness at preventing Zn deficiency. Granular Zn sources should have a minimum of 50 percent water solubility for optimum effectiveness. Sources with water soluble Zn concentration < 50 percent should either not be used or be applied at higher (15 to 20 pounds Zn per acre) Zn rates. It is very important that growers know the source/type of granular Zn that they are purchasing. The percent of water-soluble Zn is not always provided on Zn fertilizer labels but can be determined by a qualified laboratory.

Preplant and Delayed-Pre Zn Application

Granular Zn may be blended with P and K fertilizers and applied before planting. Preplant and delayed-preplant surface applications of Zn fertilizer are equally effective for dry-seeded rice. Zinc fertilizers might perform best when surface applied to fields that will be water-seeded. Root development under water-seeded conditions is slow; therefore, Zn fertilizer placement may be more critical for proper plant uptake. Highly water-soluble, granular Zn sources intended for soil application should be applied at 10 pounds Zn per acre. To calculate the total amount of Zn fertilizer required, divide 10 pounds Zn per acre by the guaranteed Zn analysis (i.e., 31 percent = 0.31) of the fertilizer. For example, 10 pounds Zn per acre of a Zn fertilizer having an analysis of 36 percent Zn requires 27.8 pounds of fertilizer to obtain 10 pounds Zn per acre [10 pounds Zn ÷ (36 percent Zn ÷ 100)]. Although the total uptake of Zn in a mature rice crop is less than 1 pound per acre, 10 pounds Zn per acre are required for adequate and uniform distribution of Zn fertilizer granules in the soil. Fertilizers with a lower guaranteed Zn analysis provide better distribution of fertilizer granules compared to higher analysis fertilizers with similar particle size.

Management Key

Granular Zn fertilizers with high water-soluble Zn content should be applied preplant to build soil test Zn when soil pH is > 6.0 and soil test Zn levels are Very Low.

Table 9-27. **Suggested zinc fertilizer sources and rates.**

Fertilizer Source	Actual Zinc lbs/A
Organic chelates EDTA, DPTA, etc.	1.0
Organic complexes ligno-sulfonates, phenols, citrates mixtures, etc.	2.0-2.5
Inorganic sulfates, oxysulfates liquids such as nitrates and chlorides	10.0 2.0-2.5

Table 9-28. **Approximate Zn content and volume in quarts of liquid Zn fertilizer to supply 1 lb of elemental Zn for solutions with Zn concentrations** (Note this is general guide and the actual Zn content of liquid fertilizers will vary. Always read the fertilizer label to determine the exact composition of a fertilizer.)

Fertilizer Zn Concentration % Zn	Fertilizer Zn Content lbs Zn/gallon	Volume to Apply 1 lb Zn quarts/A
4	0.40	10.0
6	0.62	6.5
8	0.80	5.0
10	1.00	4.0
12	1.14	3.5

Research also suggests that liquid Zn sources (Zn EDTA and Zn sulfate) may also be applied shortly before or after planting (i.e., pre-emergence). Liquid sources offer the advantages of more uniform distribution, lower use rates and, depending on the source, lower fertilizer cost when compared to most granular applications. Liquid Zn sources may be compatible for tank-mixing with most herbicides but the herbicide label should always be checked and a compatibility test performed before mixing. Please refer to Arkansas Cooperative Extension Service fact sheet FSA2166, *Checking for Compatibility of Herbicide-Fertilizer Combinations*. Avoid applying herbicides and/or herbicide Zn mixtures if the rice is stressed at the desired time of application since increased injury may occur. Application of herbicides under stressed conditions may result in a loss or reduction of stand. Inorganic Zn sources (Zn sulfate) applied in the liquid form before planting or emergence should be applied at 2 pounds Zn per acre and chelated Zn sources should be applied at 1 pound Zn per acre. The lower use rates of Zn applied in this manner offer less residual or future benefit of the Zn on future crops and soil-test Zn. Therefore, this approach is recommended only on soils that have Medium soil-test Zn levels (2.6-4.0 ppm Zn).

To calculate the proper volume of a liquid Zn source to apply, determine the amount of Zn contained in each gallon of material. The fertilizer label should provide the weight per gallon of material and the percent Zn in the fertilizer. The product of these two values divided by 100 is the pounds of Zn per gallon of liquid fertilizer. For example, a fertilizer with 6.5% Zn and weighing 11.8 pounds per gallon contains 0.77 pound Zn per gallon [(0.77/100) × 11.8 pounds per gallon)] and requires 5.2 quarts per acre to supply 1 pound elemental Zn per acre.

Zinc seed treatments are also an effective means of Zn fertilization for dry-seeded rice (Table 9-29). The advantages of Zn seed treatments are potential lower cost (depending on the Zn source and rate used to treat the seed) and uniformity of application. Zinc seed treatments require from 0.25 to 0.50 pounds of Zn per hundredweight of seed. Some sources and high rates of Zn applied to rice seed may reduce germination, so caution should be used when selecting new, untested Zn sources for seed treatment. As a rule of thumb, the higher Zn application rate (0.50 pounds Zn hundredweight of seed) should be used when soil pH is > 7.0 and soil-test Zn is relatively low (< 2.6 ppm) and/or when the seeding rate will be very low (< 50 pounds seed per acre).

Table 9-29. Influence of Zn seed treatments on rice yields on two alkaline silt loam soils.

	RREC†		PTRS†	
	Yield	Tissue Zn	Yield	Tissue Zn
Zn Rate	bu/A	mg/kg	bu/A	mg/kg
Check	114	17.5	130	17.5
10 lb Zn/A‡	158	31.0	143	19.4
0.10 lb Zn/cwt††	136	16.9	145	20.2
0.22 lb Zn/cwt	146	18.5	142	20.9
0.47 lb Zn/cwt	152	20.9	163	29.7

† RREC, Rice Research & Extension Center, Stuttgart; PTRS, Pine Tree Research Station.
‡ 31% Zn sulfate (> 95% water soluble Zn) preplant incorporated at 32 lb/A.
†† Zn sulfate applied to seed - values are net seed concentration after treatment.

Source: Slaton et al., 2000. *B.R. Wells Rice Res. Studies 1999*. Ark. Ag. Exp. Sta. Res. Ser. 476.

When soil pH is > 6.0 and soil-test Zn is < 2.6 ppm, Zn seed treatments alone may not provide sufficient Zn to prevent Zn deficiency. Another method of Zn fertilization (foliar or soil-applied Zn) should be used in place of or as a supplement to Zn-seed treatments under these conditions. **The amount of Zn retained on the seed after treatment rather than the amount applied is critically important.** Zinc oxide is the form of Zn used to treat seed because it usually has a high Zn analysis and allows for the lowest volume of Zn material to be added to the seed treatment equipment. However, Zn oxide formulations must be well mixed since the Zn can settle in the shipping container and contribute to lower than desired Zn addition. Most laboratories that perform plant and soil analysis can check the Zn concentration of treated seed. Submit a half pint of Zn-treated seed in a sealable bag to a reputable lab to determine the seed Zn concentration.

Management Key

Zinc seed treatments should only be used as the sole source of Zn fertilizer when the soil test Zn is ≥ 2.5 ppm.

The best approach for management of Zn nutrition in rice may be to build soil-test Zn levels above 4.0 ppm (Mehlich-3 soil test) with granular Zn applications and use Zn-treated seed or other low cost Zn fertilization methods for insurance on future crops.

Preflood Applications

Liquid organic chelate or inorganic sources can be applied from the 2-leaf stage to five to seven days prior to flooding. Application of liquid Zn immediately before flooding is discouraged since seedling rice may be Zn deficient before flooding. Application of Zn fertilizer to rice foliage five to seven days before flooding provides time for fertilizer uptake and correction of the Zn deficiency before the seedlings are stressed by flooding. Use of chelated Zn sources is advantageous only when the plants are very small (i.e., small leaf area) and most of the applied Zn solution will contact the soil. Chelated and inorganic Zn are absorbed with equal efficiency when applied to plant leaves. However, chelated Zn sources are mobile in the soil, which aids in Zn movement and uptake by plant roots, and the chelate protects the Zn from becoming fixed (or unavailable) by the soil for a short time. The rate of Zn is very important. The minimum recommended rate for foliar Zn application to rice is 1 pound Zn per acre. Finely granulated or powdered water-soluble forms of Zn sulfate may be dissolved and applied as a solution as an alternative to liquid Zn formulations. Dry formulations of water-soluble Zn sulfate are oftentimes cheaper per pound of Zn than liquid Zn formulations.

Management Key

Granular Zn sources are best for increasing soil test Zn.

Many of the products sold as chelates are not well labeled and are often mixtures that contain a very small portion of the Zn in the chelated form. If in doubt as to the reliability of the Zn source, use the higher rate recommended for the nonchelated organic and inorganic liquids. **The disadvantage of foliar or low-rate soil applications of Zn fertilizer is they benefit only the current rice crop and do not build soil-test Zn to provide residual benefit to future crops.** Application of granular Zn fertilizers a week or two before flooding is not recommended.

Management Key

Use Zn solutions when the application will be made after emergence and before the flood is established.

Salvage Treatment for Zn Deficiency

1. Drain immediately after detecting symptoms. The interval between draining and visual recovery from symptoms is usually 7 to 14 days. Correction of the problem by foliar applying Zn fertilizer while the field is still flooded is not recommended unless the Zn deficiency is detected early, flood depth is shallow, and the Zn deficiency is not severe.
2. When new root and shoot growth are observed, apply 1 pound Zn per acre to rice foliage.
3. 3 to 5 days after Zn application, apply 100 pounds ammonium sulfate per acre and apply shallow flood.

Zinc deficiency may delay plant development by as much as two to three weeks; however, yields approaching 90 percent of normal may be expected if the delay in development does not result in additional losses due to cold weather at heading.

Delaying the initial flood (e.g., past the 5-leaf stage) may help minimize Zn deficiency on high pH soils by allowing further development of the rice root system; however, this may also increase herbicide use to control weeds.

Salinity

Salinity damage occurs mainly on rice during the seedling stage and on larger rice located on levees both prior to and after flooding. Injury results when soluble chloride or nitrate salts (i.e., calcium, magnesium, potassium, sodium, etc.) become concentrated within the root zone of the seedling rice plant. Salt accumulation is often the result of irrigation water containing high quantities of soluble salts. In addition, salinity problems are commonly associated with poor soil drainage, and some soils and subsoils have naturally high levels of soluble salts. The poor soil drainage characteristics that are beneficial for flood maintenance in rice are the same characteristics that increase the likelihood of salinity. Salinity injury occasionally occurs when the field is flushed or flooded due to the irrigation water containing high levels of soluble salts.

When soluble salts are deposited in the soil, the salts may move vertically and horizontally in the soil profile with the water. During periods of high rainfall or irrigation, salts leach downward through the soil profile, the extent of which is determined by the soil's permeability, or salts may move laterally with the flow of water. During dry periods, water is removed from the soil through evaporation and salts move up and accumulate at the soil surface. Salt accumulation at the soil surface can reduce stands in certain areas of the paddy, such as the breaks of ridges, stagnant water areas (low spots) and on the top of levees. Usually salinity damage on levees does not occur until the field is flooded. Salt accumulation on the levee tends to be greatest on the top and deep water side of the paddy. The soil surface on top of the levee may have a black, oily appearance from the accumulation of salt and organic matter that was dissolved in the soil water prior to evaporation.

Research has shown that reduced tillage may enhance salt accumulation during the seedling growth stage on soils that have a history of salinity injury. Yield reductions of as much as 20 percent have been measured as the result of reduced tillage on soils that have a history of salinity damage (Table 9-30). Thus, it may be advantageous to avoid using conservation tillage practices on soils that have a history of salinity injury.

Table 9-30. Influence of tillage on salinity and rice grain yields.

Tillage Operation	Grain Yield	Salt in Root Zone at 2-3 Leaf Stage EC†
	bu/A	(µmhos/cm)
Conventional	146	585
Chisel Plow	158	500
Para-till	159	485
No-till	130	775

† EC, Electrical conductivity measured on a 1:2 soil wt: water volume ratio.
Source: Wilson et al. 2000. *SSSAJ* 64 :1771-1776.

Plant symptoms of salinity damage are as follows:

- Plants are usually at the 2- to 5-leaf stage. Rice is relatively tolerant to salinity during germination; however, it becomes quite sensitive to salinity during early seedling development.
- Symptoms include leaf tip die-back, leaf rolling, stunting and rapid death, increased sensitivity to herbicides and reduced stand density. Salt stressed plants may turn chlorotic (yellow), with the chlorosis beginning in the youngest leaves.
- Plant analysis usually indicates an excessive level of chlorides and/or nitrates in the tissue (Table 9-25).

Soil samples taken from the affected area may show an elevated electrical conductivity (EC) along with higher than normal levels of such cations as sodium, calcium, magnesium and potassium or anions such as nitrate and chloride. Salinity problems are difficult to predict from routine soil test results since salt concentrations in the topsoil are greatly influenced by precipitation. Salinity injury may occur on soils having an EC > 400 micromhos per cm (Table 9-31) for a mixture of one part soil to two parts water.

Table 9-31. Saline and sodic soil identification parameters.

Soil Condition	All Soil Textures
Saline Soil Condition	**Electrical Conductivity, micromhos/cm†**
Normal	< 150
Excessive	> 400
Sodic Soil Condition	**% Na Saturation‡**
Normal	< 3
Excessive	> 8

† Electrical conductivity as determined in a 1 part dry soil and 2 parts water (volume:volume) mixture.
‡ Exchangeable Sodium Percentage (ESP).

Management of Saline Soils

1. Flush the seedling rice frequently with good quality irrigation water that is low in salts to minimize accumulation of salts within the root zone.
2. Flood the rice as soon as it can tolerate a flood.
3. Have irrigation water tested for quality. When possible, minimize the use of poor quality water by substituting good quality surface water for poor quality groundwater. **CAUTION:** Surface water can also be of poor quality in regards to salt content. Salts are soluble, and water that is relifted from drainage ditches or tailwater recovery systems may actually increase in soluble salt content.

Occasionally, a field may have both a nutrient (Zn or P) deficiency and a salt problem. In this situation, diagnosing both problems is important. Apply the Zn as early as possible; otherwise, flushing the rice may intensify damage from Zn deficiency while attempting to reduce salt damage. In addition, the flush water must be applied and removed in the least possible time. This may require rearranging the flood gates.

Sodic soils are different from saline soils in that they contain very high amounts of exchangeable Na. Precision soil leveling may expose subsoils that are naturally high in Na. Sodic soils have a high pH and very poor physical properties. High amounts of exchangeable Na indirectly affect rice growth by causing poor soil physical properties. Poor physical properties, such as lack of soil structure, may make stand establishment more difficult. Some of the Arkansas soils that are classified as having Natric (sodic) subsoil horizons are the silt loam soils: Foley, Hillemann, Lafe and Stuttgart. The exchangeable Na percentage (ESP) of the topsoil and subsoil test results can be used to identify potential Na problems (Table 9-31).

Diagnostic Soil and Plant Tissue Sampling

In addition to routine soil tests (0 to 4-inch depth), diagnostic soil tests for salt content (EC), sodium, pH and calcium can help determine why seedling rice is dying. Diagnostic soil testing consists of sampling both the affected and unaffected areas at different depths (e.g., 0 to 1, 1 to 2 and 2 to 4 inch depths). Be sure to pay attention to differences in soil texture when sampling. **The likelihood of correctly diagnosing the problem increases when both plant and soil samples are collected.**

Correct diagnosis of nutritional problems is not always easily performed through soil testing and visual identification of deficiency symptoms. This is especially true of precision-graded fields. Plant tissue analysis should be used to help identify the nutritional or salinity problem(s) (Tables 9-13 and 9-25). Tissue analysis is offered through the University of Arkansas for a small fee. For seedling rice, complete plants (without the roots), of both healthy and unhealthy plants, should be submitted for analysis. About 30 to 40 seedlings are needed to provide enough tissue for analysis. Quickly but thoroughly rinse fresh plant tissue with clean water to remove soil contamination. Place the healthy and unhealthy seedlings in separate paper sacks and deliver to the county Extension office. Older plants can either be submitted as entire plants or samples of the affected tissues (i.e., top or bottom leaves). Consult with a specialist to determine which plant tissues might be the best to sample based on plant growth stage and the exhibited symptoms.

Results from plant tissue and soil analysis may not be received quickly enough to salvage a sick crop, but can be used to identify the problem and take corrective measures to avoid problems in future years. A method that frequently identifies and solves nutritional problems is the application of different fertilizers to small plots within the affected area. The nutrient(s) that give a growth response identifies the nutrient(s) that are limiting and should be applied. Usually a growth response from the fertilizer applied in the plots occurs in 3 to 5 days if the field is flooded or if the fertilizer has been watered into the soil. Phosphorus-deficient rice may take longer than 3 to 5 days to respond to P fertilizer.

Fertilization and Management of Precision-Graded Soils

Precision grading of fields for improved water management is continually being performed in eastern Arkansas. A decrease in productivity often results from precision grading of silt and sandy loam soils. Typically, when soils are precision graded, topsoil is removed from areas of higher elevation and deposited in areas of lower elevation. In many cases, the subsoil material that is exposed or moved is unproductive and difficult to manage. In these areas, it is generally true that the deeper the cut, the greater the decline in crop productivity and the more beneficial it will be to invest in soil reclamation. Routine soil testing is often unable to identify the nutrient(s) that are limiting plant growth on the cut areas. The application of poultry litter helps restore lost productivity to graded soils. Realizing that some soils may be graded without a loss of productivity, application of poultry litter to these soils may not be economical unless the soil also requires P and K fertilizer. For example, clay soils do not generally exhibit reduced productivity following grading and seldom require both P and K fertilizer. Graded fields of silt loam soil that have the topsoil removed, stockpiled and replaced after the field is put to grade generally do not have as great of loss of productivity as compared to fields that do not remove/stockpile the top soil prior to grading. The following is a summation of research conducted to refine recommendations for the application of poultry litter and fertility management on precision-graded soils. Suggestions on rice crop management have also been included where appropriate.

General Fertility

Adjust the recommended N rate for the cultivar to be planted by reducing the N rate by 25 percent of the total N in poultry litter (*see previous section on poultry litter as a fertilizer source*). Litter commonly contains 2 to 4 percent N (Table 9-23). However, only about one-half of the total N in poultry litter becomes available during the first growing season and at least half of that is mineralized and nitrified prior to flooding and lost via denitrification after flooding.

Although routine soil testing may not identify specific fertility problems on precision-graded fields, soil samples should be submitted for general recommendations for P, K and Zn and to identify potential problems with pH and Na levels. Refer to the *Rice Production Handbook* sections that discuss P, K, Zn and saline and sodic soils for recommendations.

Application of at least 40 pounds P_2O_5 per acre is recommended on precision-graded soils because the P content of many Delta subsoils is very low. If the soil-test P is high (> 50 ppm) P may not be needed. Rice growing on graded soils frequently responds to P fertilization (Table 9-32). The application of both poultry litter and P fertilizer may produce yields in excess of those obtained when either material is applied alone, especially on deep cuts.

Inorganic fertilizer (P, K, Zn and S) has in some cases increased productivity of precision-graded soils (Table 9-33); however, yield responses to commercial fertilizer applications alone have been inconsistent and are not always as great as those from poultry litter. Trial results also indicate that inorganic fertilizer is less effective on soils with deep cuts (> 6 inches). Apply inorganic fertilizer in amounts recommended by soil-test results, in addition to poultry litter. Diagnostic soil testing and plant tissue analysis may be useful to correctly identify nutritional problems in unproductive field areas during the growing season.

Table 9-32. Rice yield response on precision-graded silt loam soils to poultry litter and P fertilizer.

Treatment	Grain Yield		
	Lewis Farm	Connor1 Farm	Connor2 Farm
rate/A	bu/A		
Control	40	106	88
46 lbs P_2O_5	52	124	121
2000 lbs litter	114	129	142
46 lbs P_2O_5 + 2000 lbs litter	101	135	164

Table 9-33. Rice grain yield response comparing inorganic fertilizers and poultry litter on precision-graded silt loam soils.

Location/Year	Grain Yield		
	Control	Inorganic Fertilizer	Poultry Litter
	bu/A		
Lewis, 1989†	40	73	114
Connor1, 1989†	106	113	129
Connor2, 1989†	88	144	142
Connor, 1990‡	50	80	88
Dunklin East, 1992††	9	32	80
Dunklin West, 1992††	37	93	99

† Litter: 2000 lbs compost/A; Inorganics: 1 lb Zn (Zn EDTA) + 2 tons gypsum + 46 lbs P2O5 (TSP)/A.
‡ Litter: 2000 lbs fresh litter/A; Inorganics: 1 lb Zn (Zn EDTA) + 20 lbs S (elemental S) + 72 lbs K2O (KCl) + 46 lbs P2O5 (TSP)/A.
†† Litter: 2000 lbs fresh litter/A; Inorganics: 300 lbs Rainbow Mix/A (10/14-4-11(S)-2(Zn)).

Management Key

Poultry litter is currently the only soil amendment that is recommended for restoring the productivity of precision-graded soils.

Products sold as soil amendments often claim to restore the productivity of precision-graded soils. The University of Arkansas has compared some of these products to poultry litter in field tests and found that they are not the equivalent of poultry litter and are oftentimes inferior to inorganic fertilizer application. Biosolids and other animal manures may be useful for reclaiming graded soils, but have not been evaluated in replicated research.

Rate of Poultry Litter

Poultry litter is a viable source of P and K on undisturbed soils, but the most unique benefit of litter is restoring lost productivity to subsoil that has been exposed by land leveling. Numerous research studies indicate that poultry litter rates less than 1,000 pounds per acre are inconsistent in producing significant yield increases on precision-graded soils (Table 9-34). Consequently, no less than 1,000 pounds of litter (dry weight basis) per acre should be applied to graded soils. When applying litter, adjust the application rate to compensate for the moisture content of the litter. For example, 1,000 pounds of fresh litter at 30 percent moisture contains about 300 pounds of water and 700 pounds of litter. Poultry litter data included in Tables 9-32 through 936 refer to dry weight litter rates.

Research shows that spring applications of litter produce higher rice yields compared to fall applications of equal amounts (Table 9-35). Results also indicate that pound for pound, fresh, composted and pelletized litter produce equal yield responses (Table 9-36). Since timing of poultry litter influences yield response, the frequency of litter applications is also important to maximize production in future years.

A single application of litter after leveling produces higher yields for several years compared to precision-graded areas which did not receive any litter. Litter has a small residual effect and may increase production for several years. The greatest benefit of litter applications to grain yield occurs the first year (Table 9-37). Grain yields were lower for the second year after litter application when no additional litter was applied.

Table 9-34. Rice grain yield response to various poultry litter rates in 1992 and 2004.

Location	Grain Yield					
	Poultry Litter Application Rate (dry weight basis)					
	0	250	500	750	1000	2000
	bu/A					
Arkansas County-East†	29	68	65	83	82	103
Arkansas County-West†	9	19	46	57	78	87
Prairie County‡	4	35	44	--	73	114
Poinsett County‡	77	94	109	--	125	137

† Composted poultry litter (Unpublished data, 1992).
‡ Mean of Fresh and Pelleted litter (Unpublished data, 2004).

Table 9-35. Grain yields of fresh poultry litter applied in the spring at five rates on shallow and deep cuts of a precision-graded field near Lodge Corner, Arkansas.

Litter Rate	Grain Yield			
	Shallow Cut (< 6 inches)		Deep Cut (> 6 inches)	
	Spring†	Fall	Spring	Fall
lbs/A	bu/A‡			
0	37		9	
1000	86	58	45	5
2000	99	79	80	22
4000	111	80	98	47
6000	102	88	107	73

† Fresh litter applied in October (fall) and June (spring) on a dry weight basis.
‡ Field seeded with Lemont rice on June 16, 1992.

Table 9-36. Comparison of rice grain yields when fresh and composted poultry litter were applied in the spring on a precision-graded field†.

Litter Rate	Grain Yield	
	Litter Source‡	
	Fresh	Composted
lbs/A	bu/A	
0	37	
1000	86	94
2000	99	103
4000	111	110
6000	102	102

† Field seeded in Lemont on June 16, 1992, near Lodge Corner, Arkansas.
‡ Litter applied on a dry weight basis.

Table 9-37. Rice yield response for the second year following fresh poultry litter application for two consecutive years on a precision-graded field compared to one single application at three nitrogen fertilization rates.

Litter Application Time	PF N Rate†	Grain Yield				
		Litter Application Rate, lbs/A (dry weight basis)				
		0	900	2700	5400	8100
	lbs N/A	bu/A				
1st and 2nd year	0	12	23	54	86	103
1st year only	0	12	--	22	--	31
1st and 2nd year	40	17	36	81	87	115
1st year only	40	17	--	31	--	54
1st and 2nd year	80	29	70	82	92	90
1st year only	80	29	--	70	--	80

† PF = Preflood.

Sequential litter applications may be needed to fully restore lost productivity to graded soils. Usually the deeper the cut, the longer the litter has to be applied. Shallow cuts usually require only a year or two of litter application and the deeper cuts may require three to five years of litter application for full restoration of productivity.

Management Tips

Management of rice on precision-graded fields is difficult since the severity of lost production is unknown and reasons for poor growth are not easily identified. The locations of areas which may have poor growth are often random and unknown prior to planting. Areas of poor growth may be the result of a combination of factors or due to a single nutritional problem. Due to the variability of graded soils, a complete set of management guidelines that would apply to all situations is impossible to assemble, but certain guidelines can be followed to reduce spending large amounts of money to produce a low yield.

Before starting the leveling process, study the county soil survey maps to determine the soil series within the field to be precision-graded. Web (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm) soil survey reports provide the physical and chemical properties of the topsoil and the subsoil which may be exposed. This helps pinpoint certain problems that may be present after leveling. Further information can be obtained by soil sampling the topsoil and the subsoil to the depth that the field will be graded. The use of global positioning systems (GPS) and grid soil sampling of both topsoil and subsoil can pinpoint areas in the field that may present problems if the topsoil is removed via precision grading.

Cultivar selection is very important for precision-graded fields. Select a cultivar that has good grain and milling yield potential but has a low cost of production. Semi-dwarf cultivars usually have higher production costs for weed control, N fertilization and sheath blight control compared to taller cultivars. Reduced growth may intensify yield reductions caused by sheath blight and nutritionally stressed plants may also be more susceptible to yield losses from blast infections. Nutritional disorders associated with graded fields often delay maturity; therefore, timely seeding is also important. Poor soil physical properties (i.e., soil structure) regularly occur in graded fields. This may affect seedling emergence and flushing frequency to establish an adequate stand of rice. Consider a cultivar that has excellent seedling vigor and seed treatments that aid in quick, uniform stand establishment. Hybrids are excellent choices for graded fields due to their excellent disease resistance, yield potential, seedling vigor and extensive root systems that allow them to take up nutrients in deficient or problem soils better than conventional varieties; however, ensure an adequate seeding rate and subsequent plant stand to achieve better results.

A preemergence or delayed preemergence residual herbicide may provide effective and economical weed control. However, some residual herbicides are not labeled for use on first year precision-graded fields or caution that increased injury may occur from herbicide application. Always read the entire label. Stressed rice seedlings may also be sensitive to contact herbicide applications, resulting in excessive injury or reduced stands. Observation of winter vegetation growth and previous crops (if any) may help identify field areas that have poor production prior to seeding. If this is the case, application of higher rates of litter to these identifiable areas may be helpful. Diagnostic soil tests may also be submitted as an aid to identify the problem.

Chapter

10

Water Management

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An adequate supply of good quality irrigation water is needed for optimum rice production. Proper management of irrigation is critical for overall profitability, management of diseases (such as rice blast), nutrient management (such as nitrogen and phosphorus), weed management and insect management. Growers need to have a good grasp of the capabilities and limitations of their irrigation system to ensure rice can be flooded in a timely manner. Knowledge of the quality and quantity of irrigation water is required for proper water management.

Determining Water Needs

A water supply is adequate for a given field if you can:

- Flush in two to four days;
- Flood in three to five days; and
- Maintain a continuous flood for the entire season.

Management Key

Flush if necessary for stand establishment or weed control.

Recommended minimum and desired pumping rates (gallons per minute per acre [GPM/acre]) are based on different soil textures (Table 10-1). To determine pumping rate for your field, multiply your field acreage by the value given for your soil type (e.g., 50-acre sandy loam field times 25 GPM/acre = 1,250 GPM). If you already know your pump capacity and field acreage, Table 10-2 can be used as a guide for determining whether your pump capacity is sufficient to maintain an adequate flood on your field. For example, if a well is pumping 1,200 GPM and rice is grown on a silt loam soil with a pan, this well should not be used to irrigate more than 120 acres of rice. Since most fields

Table 10-1. **Recommended pumping rates for different soil textural groups.**

	(GPM†/Acre)	
Soil Textural Group	Minimum	Desired
Silt loam – with pan	10	10
Sandy loam	15	25
Silt loam – no pan	10	15
Clay and silty clay	15	20

† GPM = gallons per minute.

Table 10-2. **General guide for irrigable acreage for different soil textural groups at various pump capacities.**

	Irrigable Acreage			
Pump Capacity (GPM)†	Silt Loam – With Pan	Silt Loam – No Pan	Clay and Silty Clay	Sandy Loam
400	40	27	20	16
600	60	40	30	24
800	80	53	40	32
1,000	100	67	50	40
1,200	120	80	60	48
1,400	140	93	70	56
1,600	160	107	80	64
1,800	180	120	90	72
2,000	200	133	100	80
2,200	220	147	110	88
2,400	240	160	120	96
2,600	260	173	130	104
2,800	280	187	140	112
3,000	300	200	150	120

† GPM = gallons per minute.

may have more than one soil texture, use these pumping rates only as a general guide for determining needed pumping capacities.

Table 10-3 shows the operating time required to pump 1 inch of water on different size fields at different pumping rates. This is useful for estimating the amount of pumping time required for a given situation. For example, a well discharging 1,000 GPM will need 36 hours to produce enough water to apply 1 inch to 80 acres (80 acre-inches).

Management Key

Select fields that hold water adequately and keep acreage within the limits of pumping capacity.

Table 10-3. Hours of operating time to pump one acre-inch of water.

Pumping Capacity (GPM†)	Surface Acres							
	20	40	60	80	120	160	200	240
	Time (Hours)							
200	45	91						
400	23	45	68	91				
600	15	30	45	60	91			
800	11	23	34	45	68	91		
1,000		18	27	36	54	72	91	
1,200		15	23	30	45	60	76	91
1,400		13	19	26	39	52	65	78
1,600		11	17	23	34	45	57	68
1,800			15	20	30	40	50	60
2,000			14	18	27	36	45	54
2,200			12	17	25	33	41	49
2,400			11	15	23	30	38	45
2,600				14	21	28	35	42
2,800				13	19	26	32	39
3,000				12	18	24	30	36
3,200				11	17	23	28	34
3,400					16	21	27	32
3,600					15	20	25	30
3,800					14	19	24	29
4,000					14	18	23	27
4,200						17	22	26
4,400						17	21	25
4,600						16	20	24
4,800							19	23
5,000							18	22

† GPM = gallons per minute.

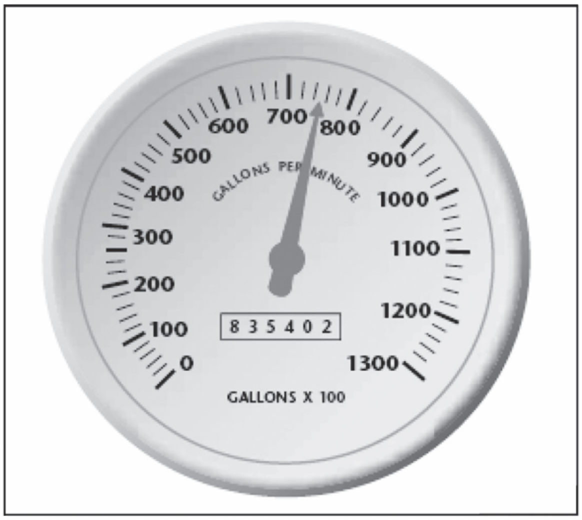
Determining Pump Flow

A good method of determining pump discharge is to use an inline flow meter. Many irrigation equipment dealers handle flow meters and can provide cost and proper installation information. There are many different styles, but the most common is a propeller-style mechanical flow meter. Currently, cost-share is available from the Natural Resource Conservation Service (NRCS) for flow meters. Proper installation is very important to ensure accurate readings and good service from the flow meter. It is most desirable to have at least 5 to 10 feet (sometimes more) of straight pipe before any bends or flow direction changes for accurate reading. However, even when this criterion cannot be met, results are still more accurate with a flow meter than with manual measurements. Flow meters measure both flow rate and the total volume of water applied (referred to as a totalizer).

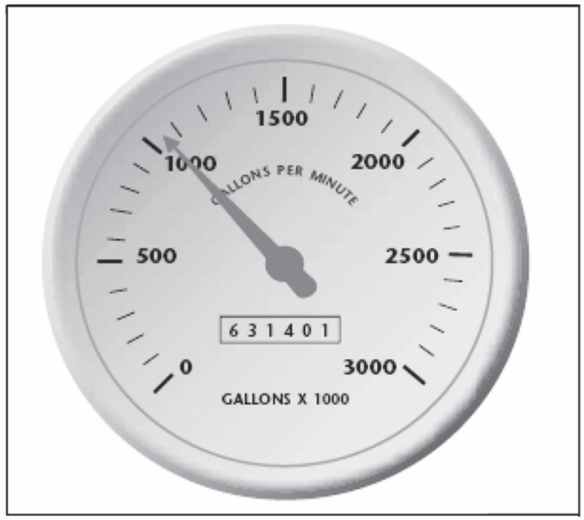
While most flow meters are permanently installed, a portable flow meter can be used to monitor the flow of more than one pumping plant. Most flow meters are equipped with a totalizer that records the total quantity of water pumped much like an odometer for a vehicle. This provides useful water management information that can also be used to document irrigation water requirements. Flow meters can be ordered with many different totalizer measurement unit types, such as gallons, acre-foot and acre-inches. Acre-inch totalizers are

Table 10-4. Hours of operating time to pump one acre-inch of water.

Volume	equals
1 gallon (gal)	8.33 pounds (lbs)
1 cubic foot (ft^3)	7.48 gal
1 acre-foot (ac-ft)	325,851 gal
1 acre-inch (ac-in)	27,154 gal
1 ac-in	3,630 ft^3
Flow	**equals**
1 cubic foot per second (cfs)	448.83 gallons per minute (GPM)
1 cfs	1 ac-in per hour
1 GPM	0.00223 cfs
1 GPM	0.00221 ac-in per hour
1 liter/second (L/s)	15.83 GPM
1 cubic meter/minute (m^3/min)	264.2 GPM
1 cfs for 1 hour	1 ac-in
542 GPM for 1 hour	1 ac-in

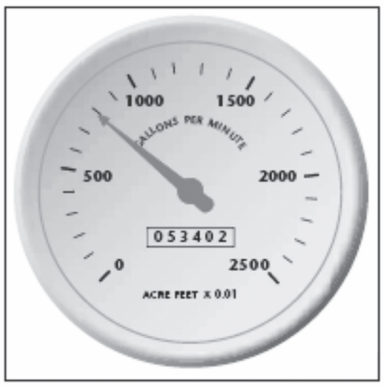


Standard 8-inch dial face with gallons totalizer. Add two zeros to the six-digit number.
Dial face reading = 83,540,200 gallons.

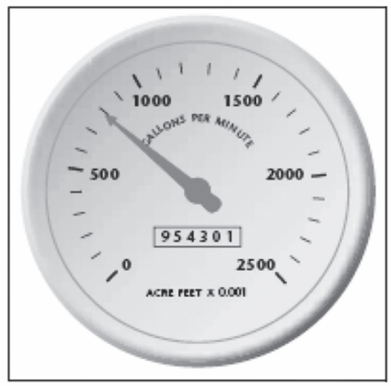


A 10-inch dial face with gallons totalizer. Add three zeros to the six-digit number.
Dial face reading = 631,401,000 gallons.

Dial with cubic feet per second indicator and acre-ft totalizer. Place a decimal point three places to the left.
Acre-ft = 835.402



Acre-ft totalizer. Place a decimal point two places to the left.
Acre-ft = 534.02



Acre-ft totalizer. Place a decimal point three places to the left.
Acre-ft = 954.301

Figure 10-1. **Flow meter dial types and how to read them (Source: Sheffield and Bankston 2008. LSU AgCenter Pub. #3082, *Irrigation Flow Measurement*).**

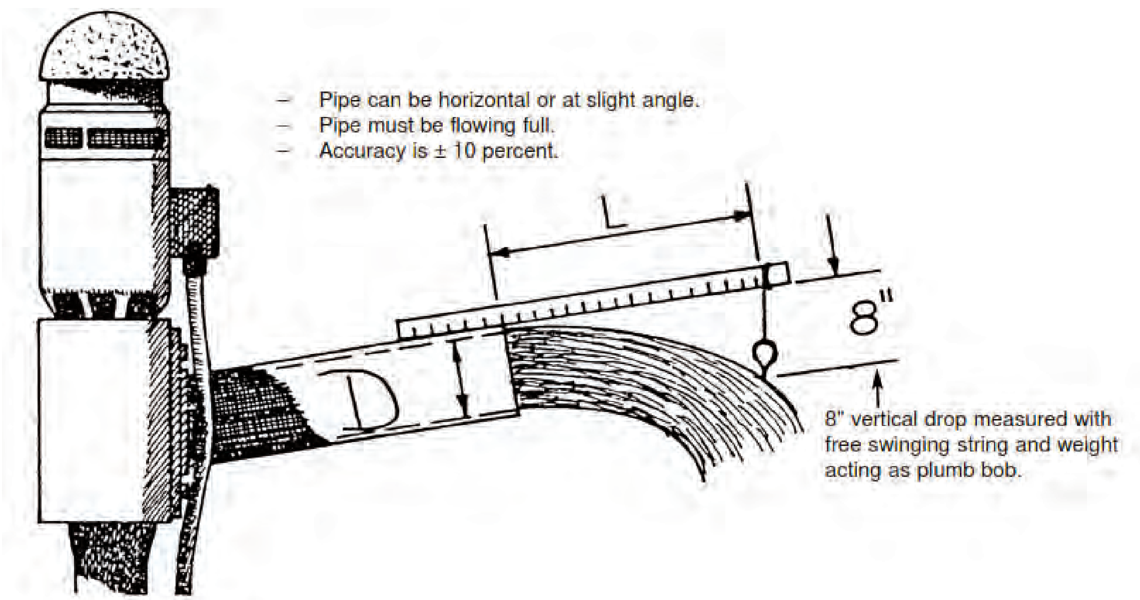
the most useful measure because the math to convert to application rate is the simplest, and the end unit is the most useful for irrigation. Table 10-4 shows conversions between different units of water measurement. The most common unit for totalizers is gallons, and there are 27,154 gallons in an acre-inch of water.

If a flow meter is not available, the discharge rate can be estimated by the plumb bob method described in the following section (Photo 10-1, Table 10-5 and Figure 10-2). When the water discharges from a vertical riser, the flow rate can be estimated with a vertical measurement (Figure 10-3 and Table 10-6).

Photo 10-1. **Manual measurement of pump flow using a yardstick and plumb bob.**

Table 10-5. **Pump flows calculated from yardstick and 8-inch plumb bob measurements.**

	Inside Diameter of Pipe (D) – Inches										
	4"	**5"**	**6"**	**7"**	**8"**	**9"**	**10"**	**11"**	**12"**	**13"**	**14"**
Inches	**Flow (GPM)**										
	64	100	144	196	256	324	400	484	476	676	784
4	96	150	216	294	384	486	600	726	864	1014	1176
6	128	200	288	392	512	648	800	968	1152	1352	1568
8	160	250	360	490	640	810	1000	1210	1440	1690	1960
10	192	300	432	388	768	972	1200	1452	1728	2028	2352
12	224	350	504	686	896	1134	1400	1694	2016	2366	2744
14	256	400	576	784	1024	1296	1600	1936	2304	2704	3136
16	288	450	648	882	1152	1458	1800	2178	2592	3042	3428
18	320	500	720	980	1280	1620	2000	2420	2880	3380	3920
20	352	550	792	1078	1408	1782	2200	2662	3168	3718	4312
22	384	600	864	1176	1536	1944	2400	2904	3456	4056	4704
24	416	650	936	1274	1664	2106	2600	3146	3744	4394	5096
26	448	700	1008	1372	1792	2268	2800	3388	4032	4732	5488
28	480	750	1080	1470	1920	2430	3000	3630	4320	5070	5880
30	512	800	1152	1568	2048	2592	3200	3872	4608	5408	6272
32	544	850	1224	1666	2176	2754	3400	4114	4896	5746	6664
34	576	900	1296	1764	2304	2916	3600	4356	5184	6084	7056



Measuring Procedure: Extend yardstick parallel with discharge pipe until 8" plumb bob barely touches the water stream. Measure length (L) and pipe inside diameter (D) which is less than the nominal pipe diameter.

Formula: Gallons per minute = the inside diameter squared x the length in inches.

GPM = D x D x L

Example: Discharge Pipe – 10 inches (D)
Discharge Length – 14 inches (L)

GPM = 10 x 10 x 14
GPM = 1400

Note: Discharge pipe must be full and plumb bob length must be 8" for this method to be accurate.
See Table 10-5 for flow rates at various measurements.

Figure 10-2. **Illustration of the manual measurement of pump flow.**

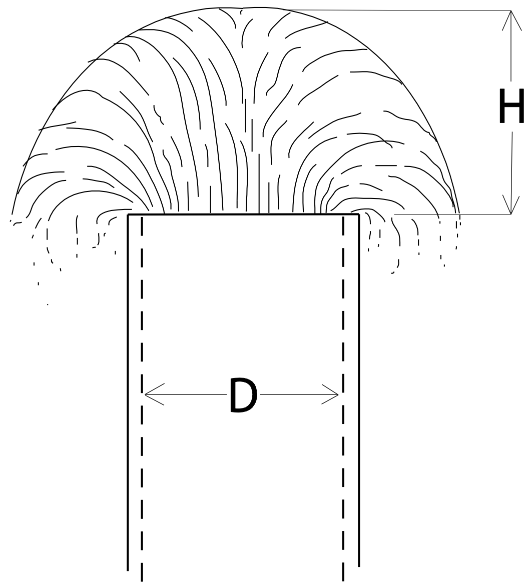


Figure 10-3. Flow from a vertical pipe or casing.

Table 10-6. Flow from vertical pipes or casings.

	Diameter of Pipe (D) (in)						
	4	6	8	10	12	14	16
Water	gallons per minute (GPM)						
3	135	311	569	950	1394	1898	2479
4	161	369	687	1115	1612	2194	2866
6	202	469	872	1415	1975	2688	3511
8	236	548	1025	1640	2281	3104	4055
10	265	621	1155	1840	2547	3466	4528
12	294	685	1275	2010	2789	3796	4958
14	319	740	1380	2170	3014	4103	5359
16	342	796	1480	2370	3224	4388	5732

Source: Irrigation Water Measurement, Louisiana State University.

However, the accuracy is usually very poor because of the difficulty in obtaining a good measurement of the vertical height. A more accurate measurement is usually obtained if a hydrant is installed on the riser, creating a horizontal discharge. A joint of pipe inserted in the hydrant stabilizes the flow and makes the plumb bob method possible.

Pumping Cost

The total cost for pumping irrigation water is influenced by several factors. Taxes, insurance, interest, depreciation, maintenance and energy must all be considered as real costs. Energy is usually more than 50 percent of the total pumping cost over the life of an irrigation pumping plant.

Table 10-7 presents typical energy use values for various energy sources and different pumping depths. Since energy prices can vary from season to season, current energy prices should be applied to the energy use values to calculate actual cost. Energy use values vary due to motor or power unit design, wear and matching to load. The values are presented as a guide for comparison.

Table 10-7. Fuel use comparison.

	Typical Fuel Consumption Per Ac-In for Different Pumping Depths†			
Power Unit Type	25'	50'	75'	100'
Electric (KWH)‡ (Conventional vertical hollow shaft)	4.0	8.0	12.0	16.0
Electric (KWH) (Submersible)	4.5	9.0	13.5	18.0
Diesel (GAL)	0.3	0.6	0.9	1.1
LP Gas (GAL)	0.5	1.0	1.6	2.1
Gasoline (GAL)	0.4	0.8	1.2	1.6
Natural Gas (CCF)	0.6	1.1	1.7	2.2
NOTE: Typical fuel consumption can vary ± 20 percent due to motor or power unit design, wear and matching to load.				

† The pumping plant performance values used in the calculations are based on Nebraska Standards and Arkansas pumping plant tests. The values for gasoline, LP and natural gas include a 5 percent drive loss, while no drive loss is considered for electric. All values assume 75 percent pump efficiency. Typical fuel consumption is based on the system performing at 80 percent of the best performance possible. Pumping depth is depth to water when pumping.

‡ GAL is abbreviation for gallon; KWH is abbreviation for kilowatt hour; CCF is abbreviation for 100 cubic feet.

Management Key

Carefully analyze differences in energy costs. Select and use another energy source where economically justified.

Because an irrigation system influences irrigation efficiency, the amount of water required for a rice field varies. Typical values for the amount of water pumped in a season have been determined for different irrigation systems (Table 10-8). The values may vary but can be used as a guide for determining seasonal water use.

Tables 10-7 and 10-8 can be used to estimate energy costs as well as to compare actual energy costs to what is presented as typical. This information can be useful for evaluation of water management practices.

Table 10-8. Typical water use amounts applied to rice by irrigation system.

Irrigation System	Irrigation Water Applied (ac-in/ac)
Zero grade	19
Precision grade	32
Non-precision grade	32
Multiple inlet	24
Sprinkler or center-pivot	19

Source: Rice Research Verification Program. Note: there is limited data on sandy soils; expect much higher water use for these soil types. No soil type difference was found in this dataset. Data from sprinkler or center-pivot rice is very limited (Source: Vories et. al., 2011).

Example scenario:

You are considering converting an existing diesel pumping plant to electricity or natural gas. The rice field soil type is predominately clay. The pumping depth for the well is 100 feet. You have a diesel power unit with diesel at $3.52 per gallon. Typical energy use from Table 10-7 is 1.1 gal/ac-in. Typical water use from Table 10-8 is 32 ac-in/ac.

Maintaining diesel unit, the estimated energy cost is:
1.1 gal/ac-in × 32 ac-in/ac × $3.52/gal = $123.90/ac

Estimated Energy Cost if Unit is converted to electricity:
Typical energy use from Table 10-7 for a vertical turbine is 16 KWH/ac-in.
16 KWH/ac-in × 32 ac-in/ac × 0.10 cents/KWH = $51.20/ac

Estimated Energy Cost if Unit is converted to Natural Gas:
Typical energy use from Table 10-7 for natural gas power unit is 2.2 CCF/ac-in.
2.2 CCF/ac-in × 32 ac-in × $1.00/CCF = $70.40/ac

For more information on pumping irrigation water, contact your local county Extension office.

Management Key

Choose the electric rate structure best suited for specific pumping situations and allow the electric company to control the well if water supply is adequate.

Well Operation

The basic approach to rice irrigation is to flush if necessary to obtain an acceptable rice stand and establish the initial flood at beginning tillering (4 to 5 leaf; 6 to 10 inches tall). A shallow flood depth of 2 to 4 inches should be maintained until about two weeks prior to harvest unless there is a reason for draining, such as for straighthead control. If the field has conditions favorable for rice blast disease or blast develops in the field, the flood depth should be increased after midseason to a depth of 4 to 6 inches to help suppress the disease. Research has shown a major reduction in the severity of rice blast when a deep flood is maintained during reproductive growth (See Chapter 11, Management of Rice Diseases). If cultivars are selected that are resistant to blast, then it is not necessary to increase flood depth.

If the well continues operating until the last levee is flooded, a significant amount of water can be wasted as runoff. Determining when to stop a well so that the water in transit will fill the remaining levee area requires experience. This depends on field size, soil type and well capacity. Table 10-1 can be used as a guide. If the pumping rate is near the recommended minimum, the water should be 90 percent down the field before the well is turned off. When the pumping rate is near the desired value, you can typically turn the well off when the water is 70 to 80 percent down the field. Some growers find that they can better establish the initial flood by filling up the bottom levee pad first and then stair-stepping the flood back up the field by raising the levee gates.

Electric companies offer a variety of rate structures that are suited to particular situations. Consult with your electric company representative to determine the best rate structure. Significant energy savings (20 to 30 percent) are usually possible when the electric company is allowed to turn off an electric service for two to four hours during the daily peak load periods (often referred to as load management programs). Some electrical utilities are allowing customers access to the control system so that pumps can be controlled by customers during the off-peak time periods, providing remote pump operation at no additional cost. Table 10-1 can be used as a guide to determine if enough pumping capacity exists to take advantage of load control programs. It is suggested to use load management for two- and four-hour shutdowns if the pumping rate is closer to the desired value than the minimum value.

Power units operate over a wide range of speeds (1,500 to 2,400 RPM). The best fuel consumption performance is usually obtained over a much narrower range of speeds (1,600 to 1,900 RPM). Recent research by the University of Missouri reported 1,350 RPM as the lowest cost of water speed and 1,550 RPM as the highest, as a general recommendation across all diesel engine types. It is best to determine the most economical operating speed and run the unit at this setting whenever possible. Other factors, such as desired pump speed and load on the power unit, must be considered. This information can be determined from pump and power unit performance specifications available through irrigation equipment dealers. Reviewing this information with a dealer can be helpful, particularly when operating a new well installation or a power unit that you are not familiar with. It is also important to make sure the gearhead ratio is correct to ensure that the pump is turning at the desired speed. A portable tachometer is a good tool for verifying both engine and pump speed.

Management Key

Service and check out the pumping plant before the pumping season to prevent costly pumping delays.

Irrigation Water Quality

While ample irrigation water is necessary for a productive rice crop, poor quality water can cause soil-related problems that negatively impact rice. Some of the predominant soil-related problems that affect rice include salinity (high soluble salts), zinc deficiency, phosphorus deficiency and excessive sodium (which causes poor soil physical conditions).

Salinity is most often associated with arid or semi-arid regions of the world, such as in the southwestern USA. However, salinity problems are common in the rice-producing regions of Arkansas in some circumstances. The poor drainage characteristics of the soils in Arkansas that allow them to be efficient for rice production also contribute to the problems associated with salinity.

Salinity results from adding salt to soils, usually in irrigation water, faster than it is removed by natural processes, such as surface runoff and downward percolation. Irrigation water is the major contributor of soluble salts in Arkansas but excessive nutrient additions from fertilizers, manures or waste materials may also contribute to the accumulation of salts. The types of soluble salts that usually contribute to salinity problems include calcium, magnesium, sodium, chloride, sulfate and nitrate.

In addition to the effect on rice production, irrigation water that contains excessive levels of chloride can lead to chloride toxicity in soybeans. Rice is very sensitive to chloride and nitrate salts at the seedling growth stage. Sodium problems are usually native to particular soils such as the Foley, Lafe, Hillemann and Stuttgart soil mapping units. However, isolated cases of water containing excess sodium have been observed. Excessive sodium may cause poor physical conditions of the soils which can interfere with crop stand establishment.

Zinc and phosphorus deficiencies are usually associated with alkaline (high pH) soils, particularly on silt loam soils. Alkaline soils are created by irrigating with water that contains high concentrations of calcium and magnesium bicarbonate. When the water enters the field, the bicarbonates are converted to calcium and magnesium carbonate (lime) which are then deposited in the field. The soil pH increases in the field where the carbonates (lime) are deposited. A soil pH gradient is usually created such that the soil pH is higher near the water inlet and decreases down the slope.

Management Key

Proper soil sampling is critical to identifying areas of the field that may require zinc or phosphorus fertilizer to prevent deficiencies. Water samples are also useful for identifying irrigation wells that may contribute to the development of these problems.

It is possible to develop both salinity and alkalinity problems in the same field. Correct diagnosis of problems concerning irrigation water quality is critical for effective management. Water quality testing is an important step in diagnosing existing problems and identifying potential problems. Several values are helpful in evaluating the quality of a particular water source. These include calcium concentration, bicarbonate concentration, chloride concentration, electrical conductivity (EC) and sodium absorption ratio (SAR). Table 10-9 provides a brief guide for evaluating water quality. The calcium and bicarbonate

Table 10-9. General rice irrigation water quality.

Water Quality Variable	Level Considered to Cause Concern†	Concern
Calcium (Ca)	> 60 ppm (> 3 meq/L)	Together can cause soil pH increases near water inlet and inflow areas; causing zinc or phosphorus deficiency in silt loam soils.
Bicarbonate (HCO_3)	> 305 ppm (> 5 meq/L)	
Electrical Conductivity (EC) [after lime deposition]	> 770 ppm (> 1200 µmhos/cm; 1.2 dS/m)	Causes high soil salinity which can injure and/or kill seedling rice.
Chloride (Cl)	> 100 ppm (> 35 meq/L)	Contributes to measured EC level (see above). High Cl alone may pose a problem for soybeans in rotation.
Sodium Adsorption Rate (SAR)‡	> 10	Causes sodic soil which has poor physical condition.

† Lower levels can cause injury in some cases.
‡ SAR = Na√[(Ca + Mg)/2], where Na, Ca and Mg are in meq/L.

concentrations provide an estimate of the amount of lime that will be deposited, and predictions can be made concerning the change in soil pH with long-term use. Electrical conductivity is a measure of the total salts that are dissolved in the water, which allows an estimate of the potential for salinity injury to rice with use of the water.

Chloride concentration is important because of the potential for chloride toxicity to soybeans and because it often is the major contributor to high electrical conductivity. The SAR is a ratio of sodium to calcium and magnesium. This number provides an estimate of how much sodium is in the water relative to calcium and magnesium. The SAR allows the prediction of whether sodic (high sodium) soils are likely to develop with long-term use of the water.

The University of Arkansas conducts water quality testing for a small fee that includes a computer prediction of any long-term effects that may result from using the irrigation water. This analysis includes effects of various crop rotations, soil texture and water management alternatives.

Once a water source has been tested, retesting is usually not necessary for at least five years. However, earlier retesting may be necessary when crop problems develop that may be related to water quality or when the pumping rate or depth changes significantly.

Management Key

Contact your local county Extension office for water quality testing if there is no recent history.

For more information on management of saline or alkaline soils, refer to Chapter 9, Soil Fertility, or to University of Arkansas Soil Test Note No. ST003, *Management of Soils With High Soluble Salts*.

Establishing Levees

An accurate levee survey is important to ensure proper control of water (Photo 10-2). Levees have traditionally been established using laser grading equipment. More growers are utilizing Global Positioning Systems (GPS) with Real Time Kinematics (RTK) to survey and design levees. A topographic survey is conducted with GPS-RTK equipment, and desktop software is used to determine levees based on the interval and smoothing. Levee designs are saved as line features for guidance and can be saved for future years.

All surveying instruments should be properly adjusted and checked for accuracy. Be careful not to exceed the operating range or distance of the equipment. A levee

Photo 10-2. **Surveying levees in a rice field.**

elevation difference of no more than 0.2 foot is generally recommended. This difference is increased on steeper fields when narrow distances between levees present a problem for combine operation. Premarking levees on clay soils and establishing levees as soon as conditions allow can reduce water loss from levee seepage. Levee gates should be installed early in the event flushing is necessary and also to provide outlets to avoid levee washouts if heavy rainfall occurs. One gate per levee is usually adequate. Two gates may be necessary in small loop levees near the water source and in larger bays (greater than 10 acres) to ensure adequate water control. If using multiple inlet irrigation, levee gates should be set higher than those for cascade flow.

Management Key

Survey levees on 0.2-foot intervals when possible. Establish a levee base as early as possible (before seeding) on clay soils. An accurate survey is critical to effective water management.

Land Grading

Precision land grading is desirable for reducing the number of levees in a field and for improving the field for furrow irrigation. Fewer levees means more productive flooded field area. If you are considering precision grading, make certain that cut areas won't expose subsoil with undesirable properties. Before grading, determine the soil mapping unit of the field by consulting your county soil survey available from NRCS. Extreme caution should be taken before grading if the soil mapping unit is Lafe, Foley, Hillemann or Stuttgart as these soils contain high sodium levels below the surface ranging in depth from 6 inches to 4 feet or greater. For these soils, take deep soil samples in 6-inch increments and compare sodium levels to the "cut sheet" to ensure that high sodium levels are not exposed in the leveling process of cutting and filling. Another option is to use "warped surface" grading where the cross grade is not zero but is adjusted with a computer to get the best fit and graded with GPS-RTK enabled earthmoving equipment.

Even for other soil mapping units, it is recommended to take several deep (greater than 6 inches) soil cores or samples, but especially if a problem soil is suspected. If soil salinity, sodium or other problems are encountered after leveling, then the addition of poultry litter has shown good results for improving rice yields on cut soil areas.

Additional information on management of precision-graded soils is given in Chapter 9, Soil Fertility. More recently, there are new land-grading techniques that can optimize the cut and fill ratios and provide an "economic" land-grading plan rather than a precision-graded field to uniformly set tolerances.

When a field is precision graded, it is recommended that a slope of no less than 0.05 percent (0.05 foot per 100 feet) should be provided in at least one direction. A slope of 0.1 percent (0.1 foot per 100 feet) is the general recommendation because it provides good drainage and is often easier to construct and maintain than flatter slopes. It is also recommended to consider putting a field to grade in only one direction (i.e., zero cross slope) if it doesn't require a significant amount of extra dirt work. Building a permanent pad or elevated road on one or more sides of a field should also be considered in the grading plan. Settling often occurs in the deeper fill areas following a grading job. If possible, touch up these areas before planting or provide field drain furrows for improved drainage. The land-grading design should consider the type of drain outlets and the number required for the field. If possible, it is best to provide an outlet point for every 20 acres.

It is not usually desirable to precision grade a field to zero slope (zero-grade) in all directions unless continuous rice production is planned. Rotation crops will usually perform better on zero-grade fields that are not over 50 acres in size. It is also critical that the perimeter ditch around the field have unrestricted drainage at its outlet(s). Another consideration for the rotation crop would be to plant on a slightly raised bed but still install a network of drain furrows in the field.

Yearly preplant field leveling or smoothing is essential for seedbed preparation, surface drainage and maintaining optimum flood depths. A landplane or float should be used to remove reverse grades, fill "potholes" and smooth out old levees, rows or ruts in a field. **Rice can germinate under either soil or water, but not both.** Therefore, maintaining a field surface that provides good drainage is important for stand establishment; controlling weeds, diseases and insects; maintaining desired flood depths; and providing a dry field for harvesting.

Water Delivery to Fields

Ditches and canals are sometimes used for water delivery to fields. There is a certain amount of water loss associated with seepage and evaporation from ditches. In addition, canals and ditches require continuous maintenance. Replacing ditches and canals with either surface or underground pipe is desirable when possible. Installing pipe not only eliminates seepage and evaporation losses but also provides more accurate water control and may return land back to production.

Management Key

Replace ditch and canal water delivery systems with pipe or tubing when possible.

Flexible irrigation tubing ("poly pipe") may be used to replace ditches and canals. The tubing is designed for low pressure and comes in various thicknesses that have different pressure capacities. If water will flow in the ditch or irrigation canal, then the tubing should be applicable to the situation. The minimum thickness recommended for this application is 9 mil. This can be an alternative when installing underground pipe is not affordable.

Multiple Inlet Irrigation

The basic concept of multiple inlet irrigation is to proportion the irrigation water evenly over the whole field at one time. The proportioning is accomplished by placing irrigation tubing across each paddy (area between levees) and releasing water into each paddy at the same time through holes or gates in the tubing. Tubing can be placed along the side of the field (side-inlet; Photo 10-3) or through the field (Photo 10-4) depending on the location of the irrigation source (Figure 10-4). This can be done on fields with straight levees and also on fields that have contour levees.

Multiple inlet irrigation provides the potential for improved water management in the following ways:

- Ability to establish flood quicker – increased fertilizer and herbicide efficiency;
- Reduce pumping time during season;
- Reduce pumping cost;
- Reduce amount of water pumped;
- Reduce water runoff from field;

Photo 10-3. Multiple inlet irrigation with tubing placed as side-inlet.

Photo 10-4. Multiple-inlet rice irrigation with tubing placed through the field.

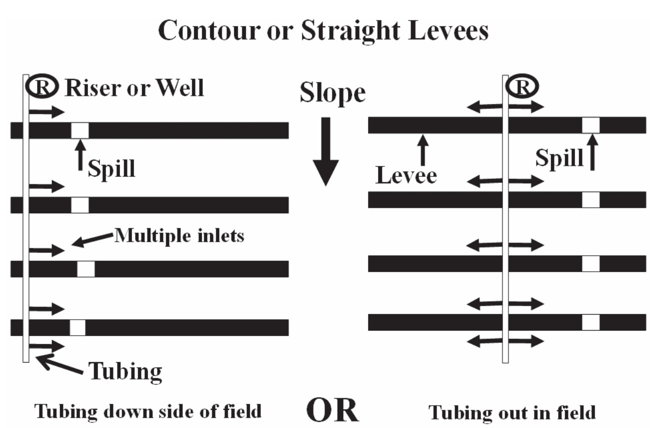


Figure 10-4. Comparison of multiple inlet irrigation setup with tubing placed along the field edge in a side-inlet design (left) and down the middle of the field in a traditional multiple inlet setup (right).

- Reduce irrigation labor;
- Reduce "cold water effect";
- Avoid risk of levee washout from over-pumping top levees;
- Reduce problems associated with scum and algae buildup in levee spills (gates);
- Reduce risk levee washout during heavy rainstorms; and
- Ability to capture rainfall.

Management Key

Set levee gates higher with multiple inlet irrigation so rainfall can be captured. Proper use of multiple inlet irrigation can reduce pumping costs by 25 to 50 percent.

Less time is required to establish a permanent flood when it is possible to put the water in at different points down the field. Once a flood is established with multiple inlets, the levee gates can be set above the desired flood depth so that more rainfall can be held on the field. Inlets to individual levees can provide more precise water control for situations, such as when there are one or more levees that seem to dry out faster. The flow to these levees can be increased independently of the other levees to avoid excessive pumping on the rest of the field. Multiple inlet irrigation is possibly more easily managed on precision graded fields that have uniform acreage between the levees, but it can still offer improved water management on non-graded fields.

One important management change that must occur to be successful with multiple or side-inlet irrigation is to limit water going over the spills from pumping and rainfall. If multiple-inlet fields are pumped up and water cascades through the spills and is managed the same as a conventional rice field, no pumping time savings will be recognized. In multiple-inlet fields, spills become emergency overflows to keep levees from failing during large storm events.

Management Key

In multiple-inlet fields, spills should be used as emergency overflows only. Don't allow water to cascade through spills when irrigating or water savings will be reduced.

Information from field demonstrations and producer experiences indicates that multiple inlet irrigation provides an average reduction in labor of 30 percent and an average reduction in pumping of 25 percent. Some producers who are using multiple inlet irrigation on sandier fields feel that it has reduced pumping by up to 50 percent. This is very possible under certain conditions, but most producers will experience about a 25 percent savings, and in some situations there may be a minimal reduction in pumping savings. Producers who aren't experiencing a significant reduction in pumping still use it for the other benefits it offers, especially the irrigation labor savings.

A few potential disadvantages or problems that can occur with multiple inlet irrigation are:

- Cost of riser bonnets (universal hydrants) and irrigation tubing;
- Initial installation of irrigation tubing and initial adjustment of the inlets (holes or gates);
- Floating, moving and twisting of irrigation tubing early in the season;
- Working around or over irrigation tubing with field equipment (i.e., spraying levees);
- Animal damage to tubing; and
- Removal and disposal of tubing.

Discussions about these problems/disadvantages with producers using multiple inlet irrigation indicate that most are willing to deal with these problems because of the advantages offered.

To establish multiple inlet irrigation for a field, a grower needs a good estimate or measurement of the pumping capacity at the field and the field acreage. The pumping capacity (GPM) is divided by the field acreage to get the ratio of GPM per acre. The estimated or measured acreage in each paddy is then multiplied by this ratio to determine the amount of water to proportion into each paddy. Following is an example of this process:

Example:

Pumping capacity = 1,500 GPM
Field Acreage = 100 acres
1,500 GPM divided by 100 acres = 15 GPM/acre
4-acre paddy: 15 GPM per acre x 4 acres = 60 GPM
7-acre paddy: 15 GPM per acre x 7 acres = 105 GPM

The required flow to each paddy is provided either through several punched holes or a few adjustable gates. Either will work, but the adjustable gate seems to be easier to manage. The most common adjustable gate has a 2.5-inch opening that can be shut completely off or left open to flow approximately 75 GPM. Producers report that the best way to manage the gates is to adjust gates on the first irrigation so that all the paddies flood up evenly. Only small adjustments should be needed during the rest of the growing season. Also, when flooding up fields, do not pump the level up to the levee gate; leave room for rainfall capture 1 to 3 inches ("freeboard").

Example:

105 GPM for a 7-acre paddy / 75 GPM per gate = 1.4 gates

Round up to 2 gates; punch 2 holes (2.5 in.); and install a blue gate in one to regulate flow.

The 9 to 10 mil tubing is recommended for multiple inlet irrigation, and the suggested sizes for different flow rates are as follows:

- 12 inch – less than 1,200 GPM;
- 15 inch – 1,200 to 2,200 GPM; and
- 18 inch – greater than 2,200 GPM.

When the slope is steep enough that the flow causes the water to surge in the tubing, the tubing should be choked at various locations down the slope to hold water up grade. This can be accomplished by several methods including choke ropes, clamps, half barrels, etc.

Management Key

A rule of thumb is that each 2.5 inch hole or blue gate provides a flow of 75 GPM.

The tubing is usually placed over the levees or along the side of the field on the permanent pad. In both cases, it is recommended that the tubing be placed in a shallow trench when it is installed to prevent the pipe from rolling and twisting. In some fields where an outside levee is pulled, it is possible to place the tubing in the borrow ditch on the inside of this levee. When crossing the levees, the tubing should go straight over without any angle in order to avoid twisting of the tubing. On firm levees, some of the levee top should be knocked off into the barrow ditch to provide a smooth ramp across the ditch so the tubing won't twist. The tops of fresh or sandy levees should not be knocked off. They will usually settle enough from the weight of the water and tubing, so some soil should be shoveled from the field into the barrow ditch. On sandier levees it may be necessary to put a plastic spill under the tubing at the levee crossing to better avoid levee washout.

If the tubing is laid further out in the field, a short pipe might need to be placed under the tubing at the low side of each levee pad, as a culvert, to ensure water can flow under the tubing. When placed out in the field, the tubing is more likely to float and move which can cause the tubing to twist at the levee. To help prevent unwanted movement, some type of stake can be placed on both sides of the tubing, or a piece of PVC pipe can be driven through the tubing. Once the rice increases in size, it will help keep the tubing from moving.

When the tubing is laid on the permanent pad, it is critical that it be placed on the flat area in a shallow ditch to avoid rolling or twisting. In this application, the water will tend to flow to the low end of the tubing. It may be necessary to make some humps under the tubing with mounded soil, pipe, buckets, barrels, etc., as it goes down the slope to help hold the water back to the high side of the field. This can also be accomplished by using some type of rope or strap around the tubing to squeeze or choke down on the tubing in order to restrict the water flow. It is also recommended that small holes be punched in the air pockets that form in the tubing once it is laid. These holes can be punched with pencil or ink pen points, wire flags, toothpicks, etc. The idea is to punch a small hole rather than cut the tubing, so caution has to be taken if a pocket knife is used.

Furrow-Irrigated Rice

Furrow-irrigated rice presents unique challenges to rice production but, in the right situations, can be done successfully. Furrow-irrigated rice (a.k.a. "row-rice") is most suitable on fields that are difficult to maintain a flood or severely sloping land that requires many levees. Often these severely sloping fields have levees so close that there is effectively very little paddy rice in the field. This system eliminates the need for levees, which reduces labor, facilitates easier harvest and may reduce wear-and-tear on harvesting equipment. Further, interest has increased on precision-graded land with an interest in minimizing equipment passes and overall management costs.

Photo 10-5. **Furrow-irrigated rice field at grain fill with rice drilled at an angle across beds.**

Cultivar Selection

In furrow-irrigated rice, blast disease is of serious concern. Therefore, it would be wise to select a cultivar that is less susceptible to blast. Choose a hybrid or select a less-susceptible variety that makes disease easier to manage with a fungicide. **Please note that in some situations, a disease such as blast may not be effectively managed with fungicides.**

Standard cultivar performance trials do not provide dependable predictions of performance for row rice production. Modern breeding programs focus on cultivars intended to perform optimally in flooded conditions – these cultivars may not necessarily perform similarly in the absence of a flood (see Table 11-1 for cultivar reactions to diseases).

The general expectation is that similar yields to conventional rice production can be achieved, but growers should be prepared for a 10 percent yield reduction in row rice production depending on field conditions and management capabilities. The goal of this system is to achieve increased profit margins by reducing input costs in other areas that offset the potential yield loss.

Seed Treatments

Insecticide and fungicide seed treatments should be used in upland rice. Rice water weevil is less of a concern than in flooded rice, but grape colaspis and billbug can be incredibly damaging in upland rice situations. A seed treatment containing a neonicotinoid insecticide, such as CruiserMaxx® Rice, NipsIt INSIDE® or NipsIt® Rice Suite, is recommended to protect against these pests in upland rice.

Drainage is improved with the use of furrows, but much of the field will have standing water after a rain or irrigation event. In conditions with a combination of standing water and cool temperatures, seedling diseases can negatively impact rice growth and lead to stand loss. Fungicide seed treatments provide short-term protection to combat and allow for plants to "outrun" seedling diseases.

Planting Furrow-Irrigated Rice

Furrow-irrigated rice should be planted at a higher density than would be recommended for the same variety in a flooded system. Add 10 percent to the seeding rate for furrow-irrigated rice. To plant furrow-irrigated rice, use a drill with spacing no greater than 7.5 inches.

Adjust the press wheels to provide adequate but not excessive down pressure for their locations relative to the furrow and the bed so that the drill "fits" the furrows and beds. That is, provide more down pressure for furrows and reduce it for beds. Oftentimes the planting depth will be deeper on the beds than the furrows, but as long as the rice is covered with soil, it should be acceptable. Avoid planting the beds too deep (greater than 1.5 inches).

Fertility Management

Nitrogen

Nitrogen efficiency in furrow-irrigated rice systems is still being evaluated. At this time, multiple options appear favorable depending on field conditions and management considerations (Table 10-10). Where possible, it is recommended that furrows be end blocked to keep tailwater on the field after an irrigation event. Collected tailwater does not have a detrimental effect as with other row crops, and the standing water can assist with management of the system. Water management will also affect nitrogen management.

In fields with shallow slopes, holding as much water in the field as possible will increase nitrogen efficiency. For these shallow sloped fields, apply the recommended

Table 10-10. Suggested nitrogen (N) management programs for furrow-irrigated rice.

Field Characteristic	Preflood† N (Prior to First Irrigation)	2nd Application	3rd Application	4th Application
Shallow Slope (0.1'/100') or less	100% preflood N‡	100 lbs urea 14 days later (upper area of field only)		
Steep Slope (0.1'/100') or greater)	50% preflood N‡	50% preflood N‡ 10 days later	100 lbs urea 7-10 days later	
Spoon-Feed (all situations)	100 lbs urea	100 lbs urea 7 days later	100 lbs urea 7 days later	100 lbs urea 7 days later

† Preflood N timing refers to the typical 4-5 leaf rice growth stage at which the flood is normally established after nitrogen fertilizer application – this term is used for consistency across rice systems.

‡ Preflood N refers to optimum preflood N rate, NOT the rate applied prior to flood in a split application typically used for varieties in flooded rice production systems.

single preflood N rate as urea to the entire field. Approximately two weeks later, an additional 100 pounds of urea should be applied to the upper portion of the field that does not remain moist at all times – this may range from the upper 1/3 to upper 1/2 of the field.

In fields with steeper slopes that are able to hold very little water, the strategy necessarily changes, and "spoon-feeding" is preferred. In these situations, dividing the N fertilizer into smaller, more frequent applications is recommended. At the 5-leaf stage, apply 100 pounds of urea and irrigate the field. After this, make additional 100-pound urea applications weekly, for a total of four applications – it is preferred that each application go out immediately prior to an irrigation event.

Another alternative is to apply half of the single preflood N rate prior to the first irrigation, with the remainder applied 10 days later as plant N demand increases. Finally, apply an additional 100 pounds of urea near midseason and at least 7 to 10 days after the previous N application.

If there are doubts about the water and field management, then more frequent and smaller N applications should be used.

Management Key

Furrow-irrigated rice requires, at minimum, an additional 100 pounds of urea than flood irrigated rice to achieve maximum yield potential.

Phosphorus

Phosphorous availability to rice is significantly increased when a permanent, continuous flood is applied. Therefore, when using furrow or overhead irrigation methods, P deficiency might be more prevalent in areas with high pH (>7.0). Soils that have a combination of low soil test P and high pH should be monitored closely for P deficiency symptoms, especially following N applications when rice experiences periods of rapid growth.

Weed Management

The lack of a flood changes weed management for rice considerably. However, repetitive irrigation can increase herbicide activation, and ground-rig applications are possible. This may call for multiple residual herbicides to be applied slightly later in the growing season to compensate for the lack of weed suppression accomplished by the establishment of a permanent flood.

A good program for conventional rice in upland conditions may include Command applied at planting as a pre-emergence herbicide; followed by Propanil + Bolero® early post-emergence; followed by Ricestar® HT + Facet® or a similar program that provides residual grass control multiple times throughout the season. Permit® or Permit Plus® should be included as needed for nutsedge control. The reduced need for aquatic weed control in furrow-irrigated rice is often replaced by the need for multiple applications of grass and broadleaf herbicides. Care should be taken to follow labeled cut-off dates and timings for certain herbicides and pre-harvest intervals (see MP44, MP519 or product label).

For Clearfield® rice in furrow fields, Command followed by Clearpath®; followed by Newpath®; followed by Beyond® may be a sufficient program. Many producers find the length of residual offered by Newpath® in Clearfield® rice to be a good fit in furrow and overhead irrigated scenarios; however, care should be taken not to rely solely on the ALS chemistry to prevent resistance.

Note: Mentions of specific products do not constitute endorsements and are only provided as examples.

Disease Management

Aerobic conditions created by upland rice production are more favorable for development of rice blast disease. There is known risk to planting fields to cultivars rated very susceptible, susceptible or moderately susceptible for blast. The safest option is to select a highly resistant cultivar, as fungicides may not be able to control neck blast on furrow-irrigated rice under some conditions for susceptible cultivars.

All commonly grown varieties have some level of blast susceptibility and should be scouted regularly to manage for this disease – even more so than flooded fields. Upland rice fields can be more easily managed with resistant cultivars (i.e., hybrids). Do not forget, a new pathogen race may even attack resistant rice cultivars.

In an upland rice production system, you need to be prepared to treat with a fungicide unless resistant cultivars are used. In a blast season, upland rice should be managed very carefully because of its increased susceptibility to blast disease. Two well-timed fungicide applications should be made: the first as heads begin to emerge from the boot (boot split to 10 percent heading) and the second approximately 7 days later when ~70 percent of the head is out of the boot.

Sheath blight and other minor diseases are typically of little concern in upland rice. However, cultivars susceptible to kernel smut and false smut will still require preventative treatments, particularly if the season is cool and wet. Moreover, remember that these two diseases are aggravated with high nitrogen fertility and late planting, especially false smut.

See Table 11-2 for a list of disease ratings for selected cultivars. Extreme care should be taken if growing a cultivar susceptible (S) to blast. Cultivars rated as very susceptible (VS) should not be considered for production under upland conditions.

Management Key

If planting blast-susceptible cultivars in furrow-irrigated rice, multiple fungicide applications are needed for management of blast disease but still may not be sufficient in certain situations.

Insect Management

As mentioned earlier, the use of an insecticide seed treatment is strongly recommended in furrow rice. Grape colaspis can result in significant stand loss (and the larvae feed underground, so no foliar options are available). Insecticide seed treatments will protect plants from rootworm and wireworm infestations, which can be a problem in furrow rice. Also, billbugs tunnel into rice plants near the base and can result in blank heads – severe infestations have been observed causing 10 percent yield loss across the field.

Insecticide seed treatments should help reduce issues with this pest. Neonicotinoid seed treatments (CruiserMaxx Rice or NipsIt INSIDE) may be the best options for upland rice. Rice stink bug (RSB) management will remain similar to that for flooded rice with a threshold of 5 RSB per 10 sweeps the first 2 weeks of heading and 10 RSB per 10 sweeps the next 2 weeks.

Irrigation Management

Irrigation

Shallow beds should be used for furrow-irrigated rice. Beds should be just adequate to convey water down the furrows without breaking over. In clay soil types, the beds can be extremely shallow, because the preferential flow of water follows the cracking nature of the soil, which dominates the movement of water in a furrow-irrigated field. Thus, in a clay soil, the bed height is very forgiving. However, in silt loam soils, a bed that is too shallow will break over easily, creating water stress in unirrigated rows. If bed height is too aggressive, then the rice plants on the top of the bed will not receive adequate water if the soil seals and does not wick across the bed easily. This will limit nitrogen and water availability and also prevent herbicide activation, so bed height is critical to success in furrow irrigation.

Set implements as shallow as comfortable to ensure a successful furrow for the season. If rotating with soybeans, consider using the existing furrows or dressing them up. This will result in a firmer bed and more established furrow. Beds can be established in the fall if desired to allow for earlier planting and less spring field work. Do not double up planting on the ends near the poly pipe, and consider adjusting down pressure to help maintain furrow integrity.

Depending upon soil type and elevation change down the furrow, a wider bed may be preferable if water soaks across beds easily. Bed widths of 30 to 60 inches are acceptable; however, in silt loams that seal, it is suggested to use 30-inch beds to provide more soil area for irrigation water to contact. Bed height and width choice are driven by equipment availability, soil type and land slope. Use the combination that works best for the conditions. Larger beds on some soil types can have difficulty wicking moisture across the entire bed. In some situations with certain irrigation sources, water chloride content (salts) can evaporate from the top of the beds and cause injury to rice.

Next, fields should have adequate capacity with a reliable irrigation pumping plant to irrigate the field in 24 to 30 hours for a 2.5 to 3 acre-inches per acre set. Both gated pipe and lay-flat polypipe have been used successfully in furrow-irrigated rice. The irrigation pipeline and sets should be planned with computerized hold selection (CHS), such as Pipe Planner (www.pipeplanner.com) to ensure that water is uniformly applied across the crown of the field. Since furrow irrigation on rice is started much earlier in the season than other crops, it has been our experience that the irrigation water can erode the shallow beds much worse in rice. Lowering the max head pressure to a range of 1.5 to 2.0 feet while maintaining high distribution uniformity should help maintain furrows.

Additionally, it is suggested to use surge irrigation in furrow-irrigated rice, especially if soil sealing is experienced during the season in silt loams or in clays if set times are long or it is difficult to get the water to advance through the field. Surge irrigation improves the down-furrow uniformity, thus improving water delivery to the rice plants at the tail end of the field. If end blocking does not impound water over a significant part of the field, then surge irrigation should be used. For fields where end blocking results in a large area of impounded tailwater, a surge valve may provide less benefit. However, in either situation, a surge valve should help to keep the upper area of the field saturated longer as the irrigation water cycles from one side of the field to the other.

Manage irrigation so that only a small amount of tailwater is created, or if end blocked, terminate the advance before the water reaches the flooded rice so that the recession (remainder of the water) replenishes the flood of the end blocked furrows. Large volumes of tailwater leaving a furrow-irrigated rice field indicate a problem with water management or infiltration. Seek the corrective remedies mentioned above.

Initial research on furrow-irrigated rice has indicated that this method, when properly managed, can use 10 percent to 40 percent less water than conventional flood-irrigated rice. However, if soil sealing is excessive or sets are not managed, furrow-irrigated rice can quickly become excessively irrigated.

Water use for furrow-irrigated rice has the *potential* to be less than for flood-irrigated rice depending on rainfall, soil type and environmental conditions. It should be noted that in some studies comparing furrow and flood irrigation, it was difficult to achieve similar yields with furrow irrigation to those achieved with flood irrigation. However, variations in agronomic management of these fields may have played a greater role than simply irrigation management.

General recommendations for improving irrigation in furrow-irrigated rice include the use of end blocking the field. This can be done by blocking the drains and, in some cases, constructing a “tail levee” at the bottom of the field to back water in the field, resulting in the lower end of the field holding some level of flood throughout the season. Also, irrigation should occur more frequently in furrow rice.

Rice is different than other row crops because the rooting depth is very shallow, and thus there is much less soil water available to the plants than in other row crops. Application rates in furrow irrigation are typically between 2 to 3 acre-inches per acre, but in furrow-irrigated rice, the target application rate should be near 1.0-1.5 acre-inches per acre. Measure flow from wells or pumps to ensure adequate irrigation volumes are being applied. A surge valve can assist in getting the correct irrigation volume applied to a field or set.

Maintaining adequate soil moisture will require irrigating every 2 to 3 days, generally. Soil moisture sensors are a useful tool in furrow-irrigated rice. Watermark™ sensors or other soil moisture sensors can be used to track the soil water balance, monitor rice water demand and ensure irrigations are effective in furrow-irrigated rice.

Place sensors at shallow depths. For example, if using Watermark sensors, place shallow sensors at 4 inches or 6 inches and 8 inches. Place at least one sensor at 12 inches and/or 24 inches to monitor any subsoil moisture change. Generally, sensor readings for depths past 12 inches will not change during the season, so make decisions based on the shallow sensor readings. Sensors should be placed in the top center of the bed soon after rice emerges so sensor installation does not damage rice roots. Damaged plants may not represent the water use of undamaged plants in the field.

Irrigation in silt loams and clays should not exceed 40 cb. Zero cb is saturated, so keeping sensor reading in single digits is not recommended, but do not allow sensor readings to exceed 40 cb. A good result is keeping levels near field capacity (28 to 32 cb) or in a range of 20 to 30 cb for most soils. Experience with soil moisture monitoring has shown that even a 2- to 3-day schedule may not be adequate for periods of the season when rice plants are at peak transpiration.

Sensors are also helpful to decide if irrigation can be delayed if rain is expected in the near future. With all types of sensors, monitor the trend of the sensor readings; the upper sensors should respond to irrigation and plant water use. A good result is a repeatable pattern within a range of the sensors' readings that correlate to visual observations about crop condition.

Irrigation practices for furrow-irrigated rice will vary widely depending on soil type, field slope, irrigation capacity and the cultivar being grown. Use the tools mentioned and adapt the furrow irrigation system that is successful for the conditions.

Management Key

In furrow-irrigated rice, use shallow beds, computerized hole selection, irrigate every 2 to 3 days and monitor irrigation with soil moisture sensors. Figure out what works for your soil type.

Irrigation Termination

Little information is available for determining the timing of irrigation termination for furrow rice systems. Care should be taken not to terminate irrigation too early and risk drought-stressing plants as they fill remaining kernels. As a general rule, keep irrigating until the crop reaches maturity. Irrigation will be necessary longer in upland rice than in flooded rice – flooded fields have saturated soil that will take more time to dry out. If using sensors, stop when the plants stop using water and the trends flat-line.

Budgeting for Furrow Versus Flood Irrigation

Budgeted costs differ among rice production systems (conventional, Clearfield, hybrid and Clearfield hybrid) for flood and furrow irrigation. Expenses and revenue can vary greatly for individual fields and farming operations. Initial field setup and management are the driving factors, and the greatest differences can be seen between fields using the previous year's beds to eliminate tillage passes versus creating new beds specifically for furrow-irrigated rice.

Notable differences in costs associated with flood versus furrow irrigation are in regard to tillage and field passes, nitrogen fertilization, herbicide program, fungicide program and application costs. For certain inputs, higher costs are associated with furrow irrigation due to the inclusion of additional nitrogen to offset losses, additional herbicides to improve residual weed control, additional fungicide applications primarily for control of blast disease and additional application costs. These additional inputs may not always be needed but should be included in conservative budgets.

Sprinkler-Irrigated Rice

Sprinkler irrigation of rice is very limited in Arkansas. Although crop insurance coverage is now available to growers, an increase in interest and acreage of this production system has not been observed. Research and experience show that the best potential is either on clay or sandy loam soils that are relatively free of johnsongrass. Many silt loam soils tend to crust, which causes excessive runoff and inadequate infiltration in the soil, so deep tillage, soil amendments, manure application and sprinkler package changes may be necessary to improve infiltration. Center pivots need to be modified for use in rice, and the operation of the irrigation system and crop management are different than for other row crops. Center-pivot systems for rice should be able to provide a minimum of 7.5 GPA to grow rice and have a sprinkler package that is appropriate for rice. Most importantly, the tire package and/or traction system should be appropriate for the field conditions. Span lengths of 180 feet or less are recommended to minimize tower weights so the pivot system can traverse the wetter soil moisture conditions. In extreme cases, additional axles, track systems and boombacks are available options. Consult your pivot dealer to ensure the system will be adequate for rice production before committing to this production system.

Pivot operation is more frequent for rice than for other row crops during the vegetative stage, and be prepared to operate the pivot every day during panicle initiation and heading. A pivot that is not able to deliver adequate water either due to pump capacity, speed or breakdowns can lead to drought stress and can result in decreased yields.

Weed control is different in sprinkler-irrigated rice because the flood is not present to suppress weed pressures typically not experienced in flood-irrigated rice. The weed control program will be similar to a conventional flooded rice field, but there may be more frequent applications needed. There are fewer rescue options available, so be prompt with herbicide applications, apply when weeds are small and rotate herbicide chemistries. Pivot-irrigated rice fields should be scouted for blast and brown spot the same as in flooded fields and fungicides applied as needed. If disease pressure is expected, plant cultivars that are resistant to blast and other diseases. There is also a possibility that certain disease problems could be increased when the foliage is wetted at the frequency associated with sprinkler irrigation.

The following recommendations should be considered for sprinkler rice:

- For soils that tend to crust or seal, deep tillage, manure application, soil amendments and sprinkler package and irrigation management changes should be considered.
- Use a residual herbicide program.
- Be certain sufficient water is available during reproductive growth (after joint movement).
- Be prepared to use multiple broadleaf herbicides at midseason.
- Plant rice cultivars with blast resistance.

Additional information on pivot rice can be found at Circles for Rice, an industry supported program and web site on pivot rice by Valmont. There is a Center Pivot and Linear System Rice Production Guide that provides additional information about the mechanics of growing pivot rice that can be obtained through Valmont dealerships (www.circlesforrice.com). References to specific companies do not imply endorsement by the University of Arkansas or imply approval or the exclusion of other products or companies that provide information, equipment or services for sprinkler rice. Additionally, many of the recommendations for furrow-irrigated rice discussed above may be appropriate for sprinker-irrigated rice.

Intermittent Flood or Alternate Wetting and Drying (AWD)

What Is Alternate Wetting and Drying?

Alternate wetting and drying (AWD) is also known as intermittent flooding. AWD is the practice of flood initiation and recession. It was first developed at the International Rice Research Institute (IRRI). As a rice flood management practice, AWD is used to maximize rainfall capture and reduce irrigation pumping while maintaining grain quality and yield.

AWD consists of flooding a field to a reasonable depth and allowing the flood to naturally subside to the soil surface via infiltration and evapotranspiration. This subsidence can be a mud (or drier) consistency at the soil surface before reflooding, depending on field specifics including soil texture and irrigation capacity.

The timing, frequency and extent of the wetting and drying cycles depend on rice growth stage, prevailing weather and field conditions and grower comfort level with the practice. After holding the initial flood for 3 weeks, it is common to refrain from applying a flood for five or more days between wet-dry cycles when using AWD. A full flood is maintained at panicle initiation (green ring) and at flowering, when rice is most sensitive to water stress.

Potential Benefits

Mid-South producers have shown that when properly managed, AWD can reduce irrigation use while having no negative impact on grain yield (Massey et al. 2014). Up to 1 gallon of diesel fuel may be saved for every acre-inch of groundwater that is not pumped or is offset by the capture of rainfall (Hogan et al. 2007). Edge-of-field runoff is also reduced (Martini et al. 2013). Lastly, both methane gas emissions and arsenic levels in grain are reduced when AWD flooding is practiced where the soil becomes aerobic for a short period of time (Linquist et al. 2014).

Potential Risks

Reduced grain yield and/or quality may result from water stress and/or reduced control of pests, particularly grasses and diseases. Water stress will occur if the field is allowed to dry too much and/or if the flood is not re-established in a timely manner, as can occur with undersized wells, irrigation system failure and/or human error. Late-planted rice (late May and June) is susceptible to disease and should not be managed using AWD flooding.

Getting Started

First, determine if AWD flood management works with your conditions and management style. Determine this on a small field, using a single dry-down period similar to that used for straighthead control.

Only use AWD on fields that meet the following criteria:

1. Weed, disease and/or insect issues should be well known and low risk for AWD candidate fields. Selected fields should be low risk for difficult to control weed pressures.
2. Fields should not have a history of blast incidence.
3. AWD should not be attempted on lighter textured soils – only on silt loam and clay-textured soils.
4. AWD fields must use Multiple Inlet Rice Irrigation (MIRI) or zero-grade rice irrigation systems. A field irrigated using only levee-gate (cascade) flood distribution is not suitable for AWD. Use of MIRI ensures that flooding can be done in the least amount of time. MIRI plans can be developed by the University of Arkansas "Rice Irrigation" mobile app or the web-program "Pipe Planner™" offered by Delta Plastic.
5. The field should have the irrigation capacity to establish an initial flood in a short period of time (~3 days) using MIRI. The irrigation source should meet recommended capacity of 15 to 20 gallons per minute per acre for silt loam and clay soils. A reliable irrigation source is critical so that reflooding can be accomplished within 24 hours. Additionally, fields that can be serviced by more than one pumping plant provide assurance of this capacity. Divide fields into smaller sets to meet flood time criteria.
6. Hybrid rice offers additional protection against disease, particularly blast, and should be considered when evaluating and learning AWD until one is comfortable with the practice before attempting it with cultivars more susceptible to disease (Hardke et al. 2016).
7. Levee gates should be raised 1 to 2 inches to create freeboard between the full flood level and top of the gate; this greatly improves capacity to capture rain and reduce pumping.
8. Flood depth gauges aid in AWD flood management and are highly recommended (Massey 2012).
9. Thorough training and oversight of field personnel new to AWD flood management is highly recommended.

Pest Control in AWD

While more AWD-specific research is needed, experience suggests that pest control programs that are effective under a continuous flood also work under AWD. Follow university recommendations.

Weeds: With the effective herbicide programs now available, continuous flooding for weed suppression is not necessary in most cases (Norsworthy et al. 2008, 2011). For example, barnyardgrass control remains as effective using AWD as with continuous flooding (Scherder et al. 2002).

Insects: Follow university recommendations.

Diseases: Use of crop rotation, disease-resistant rice hybrids and varieties and preventative fungicide applications when needed are recommended.

Table 10-11. **Alternate wetting and drying (AWD) rice flood management practices for delayed flood, drill-seeded rice production in the Mid-South.**

Rice Growth Stage	Flood Status	Agronomic Activity	Comments
Planting to four-leaf	None.	Weed control: Pre-emergence plus early post-emergence herbicide program featuring residual herbicides. Disease: Seed treatment using broad-spectrum fungicide(s). Insects: Insecticide seed treatment for rice water weevil and grape colaspis control.	Follow standard university cooperative extension pest control recommendations.
First tiller (4-5 leaf rice)	Initiate and maintain flood as normal.	Apply herbicide(s) and fertilizer as normal prior to initial flood.	Hold flood for 3 weeks to stabilize nitrogen and to allow canopy closure to aid in weed suppression.
Three weeks after initial flood	AWD flood.	Begin AWD flood by halting irrigation and allow flood to subside naturally. Re-establish flood when mud appears in top third of paddy, do not allow soil to form cracks. Repeat cycle. Apply post-emergence weed control as needed, per university recommendations.	If new to AWD, begin with single dry down as recommended for straighthead control. The ultimate number of wet-dry cycles is a function of weather, field, soil conditions and producer comfort with AWD.
Panicle initiation (Green ring)	Full flood.	Establish and maintain flood 5 days before and 7 days after panicle initiation (green ring).	Rice is sensitive to water stress during this growth stage. Do not allow flood to dry.
Optional: Midseason N application	Shallow flood.	Apply mid-season N fertilizer to a shallow flood, if needed after panicle initiation AND 3 weeks after preflood N incorporation. Maintain stable flood condition for 5 days.	Resume AWD flood management after nitrogen applied.
Early to late boot	AWD flood.	Apply broad-spectrum fungicides for disease prevention, per university recommendations.	Reflood whenever mud appears in top third of paddy; do not allow soil to form cracks.
Heading and Grain Fill	Full flood.		Establish and maintain a full and permanent flood from 3 days prior to 50% heading until 25 days after 50% heading for long-grain cultivars (35 days for medium-grain cultivars).

Fertility Management

Properly managed AWD should not influence nutrient management in regard to rates and timings of fertilizer application. By following the above university guidelines for AWD, no changes are needed to nitrogen (N) fertility management. A single preflood N fertilizer application simplifies water management through the season. A continuous flood should maintain well saturated soils for a full 3 weeks following preflood N application to ensure efficient N uptake by rice plants. If a two-way split N management plan is used for conventional cultivars, the midseason N application should be applied into the floodwater, which is maintained for at least 5 days following application.

Resources

Multiple-Inlet Irrigation for Rice, 2004.
Available at http://msucares.com/pubs/publications/p2338.pdf

Multiple Inlet Approach to Reduce Water Requirements for Rice Production, 2007.
Available at http://www.ars.usda.gov/sp2UserFiles/Place/50701000/cswq-0215-174368.pdf

Video on Side Inlet Rice Irrigation, 2012.
Available at https://www.youtube.com/watch?v=XR2JNspMXkk

References

Massey et al. 2014. Farmer adaptation of intermittent flooding using multiple-inlet rice irrigation in MS. *Ag. Water Mngt*. 146: 297-304.

Hogan et al. 2007. *Estimating Irrigation Costs*. University of Arkansas Coop Ext. Ser. pub no. FSA28. Available at http://www.uaex.edu

Martini, et al. 2013. Imazethapyr and imazapic runoff under continuous and intermittent irrigation of paddy rice. *Ag. Water Mngt.* 125:26– 34.

Linquist et al. 2014. Reducing greenhouse gas emissions, water use and grain arsenic levels in rice systems. *Glob Chang Biol.* 21(1):407-17.

Hardke et al. 2016. *Arkansas Rice Cultivar Testing*, 2014-2016. University of Arkansas Div. of Agriculture, Available at http://uaex.edu/farm-ranch/crops-commercial-horticulture/rice/RIS%20176%20AR%20Rice%20Cultivar%20Testing%202016.pdf

Massey. 2012. *Installation and Construction of Rice Flood Depth Gauges*, Available at http://msucares.com/pubs/infosheets research/i1358.pdf

Norsworthy et al. 2008. Imazethapyr use with and without clomazone for weed control in furrow-irrigated, imidazolinone-tolerant rice. *Weed Tech.* 22:217–221.

Norsworthy et al. 2011. Weed management in a furrow-irrigated imidazolinone-resistant hybrid rice production system. *Weed Tech.* 25:25–29.

Scherder et al. 2002. B.R. Wells Rice Research Studies 2002. AAES Res. Series. 504. Pp. 156-164.

Irrigation Termination

Current recommendations for draining the flood from the rice fields as predicted by the Rice DD50 program is 25 days after 50 percent heading for long-grain cultivars, 30 days for medium-grain cultivars and 35 days for short-grain cultivars. While there are situations that may not require the 25-day duration, earlier draining can negatively impact rice grain yields on some fields (Table 10-12). Grain yields were substantially lower when drained 14 days after heading than when drained 28 days after heading at Stuttgart and Pine Tree. When averaged across three years and four locations, the response was consistent for all four varieties evaluated (Figure 10-5). Little rainfall and rapid soil drying conditions allowed the early drain treatments to dry below permanent wilting point (15 percent volumetric moisture content) during the time before the recommended drain time (Figures 10-6 and 10-7).

This indicates that the soil moisture became limiting during the latter part of grain filling and influenced yield. Thus, it is important to ensure adequate moisture for the rice plant throughout the grain-filling process. Some clay soils that are poorly drained may benefit from early draining. A general rule is that if fields

Table 10-12. Influence of drain timing on rice grain yields on two silt loam soils.

Drain Timing	Grain Yield			
	RREC†		PTBS†	
	2004	2005	2004	2006
dah‡	bu/A			
14	189	176	209	146
21	195	188	213	--
28	212	195	218	239
35	198	198	226	202
LSD	11	15	10	14

† RREC = Rice Research and Extension Center; PTBS = Pine Tree Branch Experiment Station
‡ dah = days after 50% heading
Source: Richards et al., 2006. p. 298-303. B.R. *Wells Rice Research Studies 2005*. Ark. Agr. Exp. Sta. Res. Ser. 540.

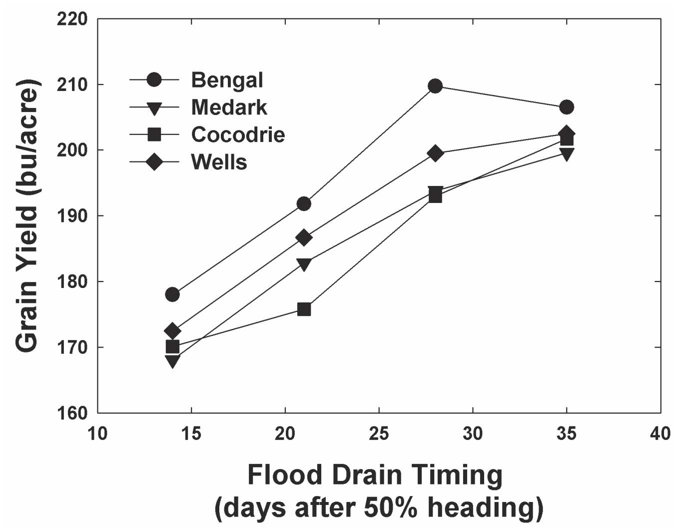


Figure 10-5. Influence of drain timing on grain yields of four rice cultivars, 2004-2006.

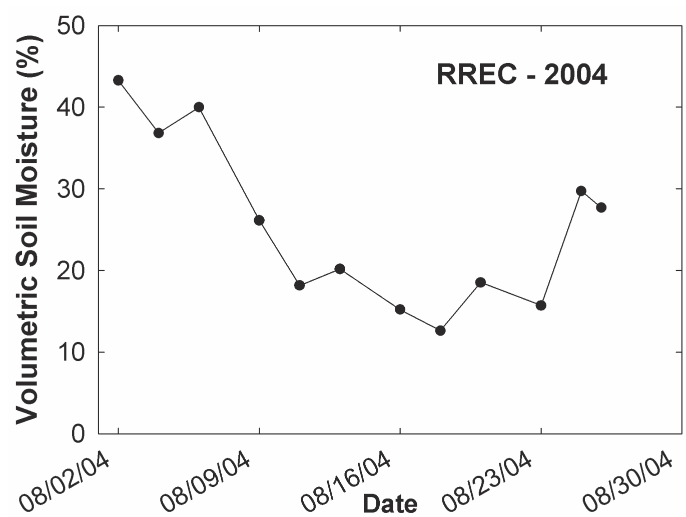


Figure 10-6. Soil moisture content following draining 14 days after heading at the Rice Research and Extension Center during 2004.

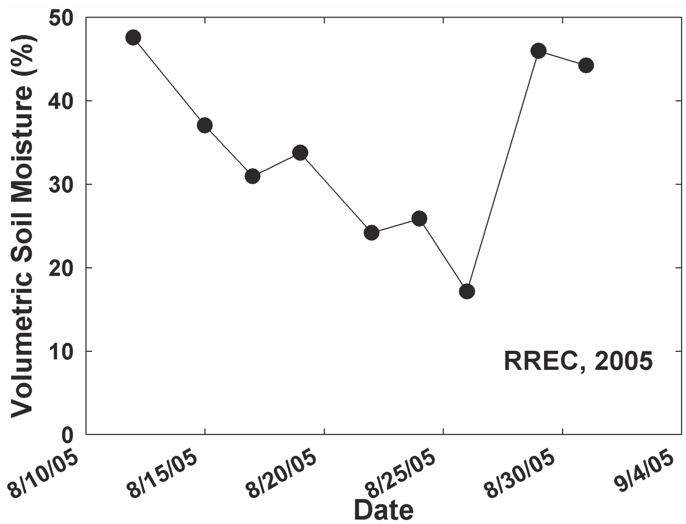


Figure 10-7. Soil moisture content following draining 14 days after heading at the Rice Research and Extension Center during 2005.

are never dry at harvest, even when little or no rainfall occurs, these fields are candidates for earlier draining. There is certainly some economic benefit to prevent rutting during harvest whenever possible. However, weather patterns are difficult to predict and caution should be used when draining early. Reduced yields resulting from early draining on clay soils has been observed when little or no rainfall occurs after draining.

Research indicates that it may be possible to stop pumping as early as 14 days after heading if the field will retain a flood for 7 to 10 days after pumping is ceased. If the weather forecast at 10 to 14 days after heading predicts temperatures above 95°F and no rain, then the flood should be maintained. There are some physical considerations for this practice. When fields are allowed to dry rather than utilizing a draining event, levees often dry to the point of reducing the efficiency of levee gate removal. Some soils become "hard" enough that removing the gates becomes more laborious than what is desired. Therefore, many producers prefer to hold the water until the time to drain.

Management Key

Drain as early as feasible to reduce pumping costs but maintain adequate soil moisture throughout the grain-filling stage.

Utilizing Surface Water for Irrigation in Critical Groundwater Areas

Critical Groundwater Designations

Several areas in rice-producing regions of Arkansas have been declared "Critical Groundwater Areas" (Figure 10-7) by the Arkansas Natural Resources Commission (ANRC) under the authority of the Arkansas Groundwater Protection and Management Act (https://www.anrc.arkansas.gov/divisions/water-resources-management/groundwater-protection-and-management-program/). A critical groundwater area may be declared by ANRC for unconfined aquifers, such as the alluvial aquifer that underlies much of Eastern Arkansas, when the water table exhibits an average decline of one foot or more annually for a minimum of five years and/or water levels have been reduced such that 50 percent or less of the formation is saturated.

While the Arkansas Groundwater Protection and Management Act allows for regulation, the ANRC has chosen to address critical groundwater areas with education and voluntary efforts such as state income tax credits and USDA financial incentive programs, such as EQIP, which are administered by the federal agency, the Natural Resource Conservation Agency (NRCS). Once an area is designated, producers who convert from ground to surface water use within the area can receive tax credits amounting to 50 percent of project costs through the Water Resource Conservation and Development Incentives Act. Landowners converting to surface water use outside critical areas are limited to a 10 percent credit.

State Income Tax Credits for Groundwater Water Conservation in Critical Areas

Under the authority of ANRC Title 14, state income tax credits (https://static.ark.org/eeuploads/anrc/title 14.pdf) are available for the following practices in critical groundwater decline areas: 1) water impoundment (reservoir) construction that creates water storage of 20 acre-feet or more with a tax credit not to exceed the lesser of 50 percent of the project cost incurred or $90,000, 2) substitution of surface water for groundwater as an irrigation source with a tax credit not to exceed the lesser of 50 percent of the

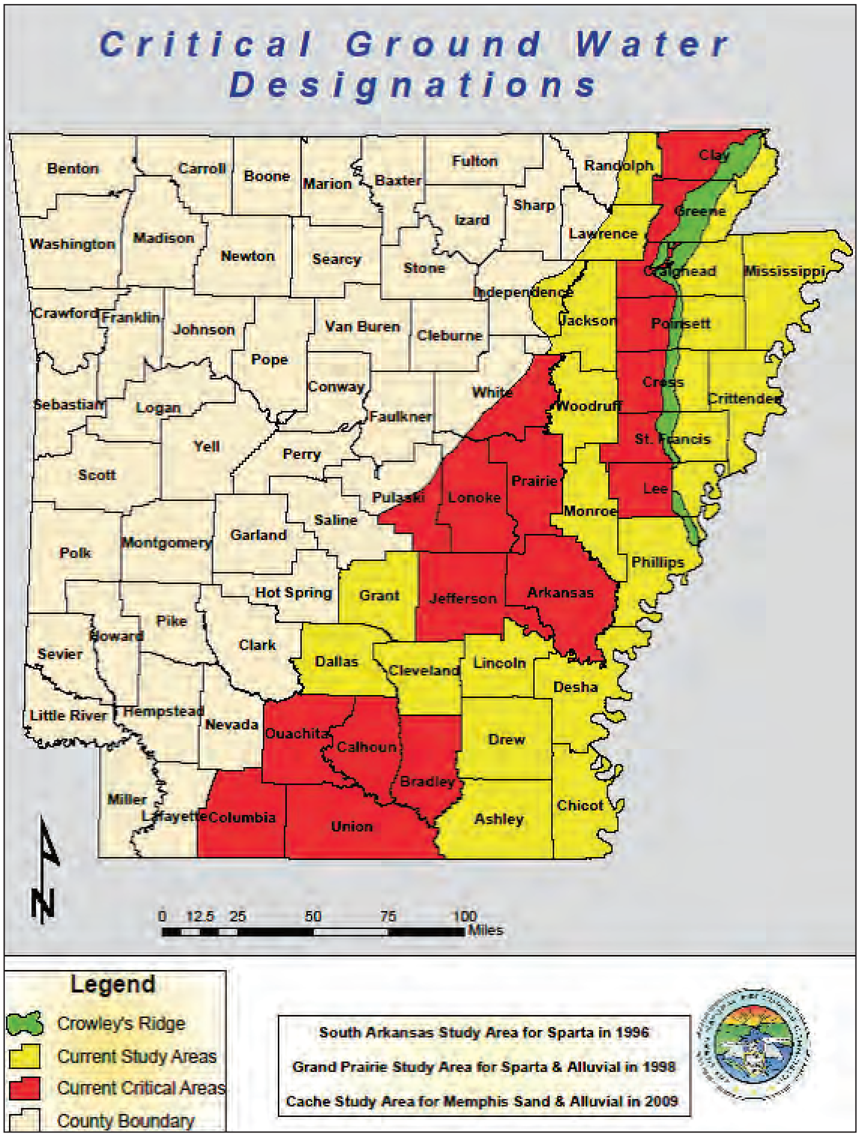


Figure 10-7. A map depicting Critical Groundwater Areas in Arkansas. Courtesy of Arkansas Natural Resources Commission.

project cost incurred or $27,000, 3) Precision Land Leveling with a tax credit not to exceed the lesser of 50 percent of the project cost incurred or $27,000, and 4) water metering.

It should be noted that the maximum tax credit for a single year is $9,000 but that credits can be spread over a maximum of nine consecutive years. Also, applications must be approved before any installation activities occur, with the exception of metering, or eligibility is forfeited. Additionally, a taxpayer qualifying for the tax credits provided under this program is entitled to a deduction in an amount equal to the project cost less the total amount of credits to which the taxpayer is entitled. For eligibility requirements, forms and more details, contact ANRC at http://www.anrc.arkansas.gov/ or (501) 682-1611.

Federal Soil and Water Conservation Financial Incentive Programs

Several water conservation practices are available for rice growers through USDA and the Natural Resources Conservation Service under the Conservation Title of the farm bill. One such program is the Environmental Quality Incentives Program or EQIP. One of the nine primary issues being addressed through EQIP is water quantity and irrigation in critical groundwater areas.

To apply for EQIP, the application must include an Irrigation Water Management Plan. Signup for these programs is continuous and involves an application process with applications being selected through an annual ranking system. For more information about these programs, contact your local USDA Service Center or visit http://www.nrcs.usda.gov/wps/portal/nrcs/site/ar/home/.

Surface Water Storage and Water Reuse

A surface collection and irrigation storage system is a planned, systematic irrigation system that allows for the collection, storage, control, movement and reuse of runoff water from previous irrigation or storm water runoff events. The NRCS offers financial assistance through their programs to design and install systems.

The ability to capture, store and reuse irrigation water on farm offers many advantages including:

- Greater control and flexibility of water supply for irrigation.
- Reduced groundwater dependence and energy costs from pumping.
- Reduced off-farm impacts on water quality by capturing sediment and nutrient losses in runoff.

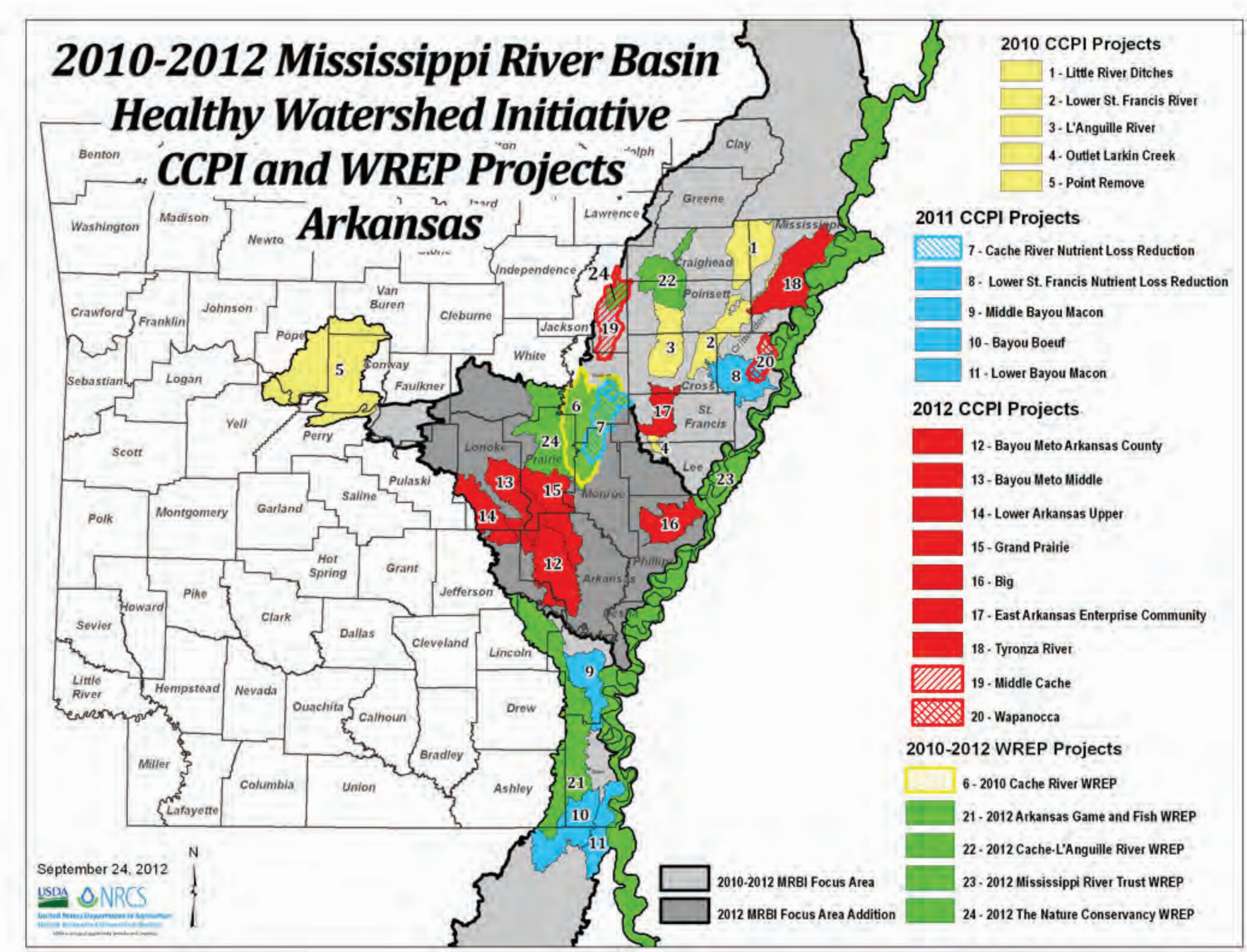


Figure 10-8. **Location of Mississippi Healthy River Basin Initiative (MRBI) project areas in Arkansas. Courtesy of NRCS.**

The main disadvantages of developing on-farm collection and surface storage are the large capital investment required for construction and taking land out of production. However, the tax credit and financial incentive programs described above can help defer costs.

While the surface water collection and storage systems may have a unique design for each different farm, they may have some common elements including an irrigation reservoir, tailwater recovery ditches, conveyance ditches or underground pipeline, pumping stations and irrigation risers. For example, a surface collection and storage system designed and cost-shared by NRCS would include several individual conservation practices linked together as a package:

- A drainage or tailwater recovery ditch at the bottom of a field (Photo 10-6),
- Surface drainage piping, main and laterals,

Photo 10-6. **A typical tailwater recovery ditch.**

- Conveyance ditches from recovery pit to storage reservoir,
- Storage reservoir (Photo 10-7),
- Pumping plants,
- Irrigation pipeline.

Photo 10-7. **An on-farm irrigation reservoir constructed with financial assistance through the EQIP program. Courtesy of NRCS.**

These components may include but are not limited to ditches, culverts, pipelines, water control and/or grade stabilization structures, or other erosion control measures, as needed. The NRCS offers technical assistance in the design of surface water collection storage systems, and their financial assistance programs allow for the cost-share of all these components.

Irrigation water stored in on-farm reservoirs has four main sources including:

- Precipitation harvesting
- Water reuse from tailwater recovery ditches that capture runoff from irrigation and precipitation
- Relift from streams, bayous and rivers for riparian right owners
- Purchase of irrigation water from irrigation districts

Keys to Water Management Success

- Keep acreage within the limits of pumping capacity.
- Select fields that hold water adequately.
- Establish a smooth field surface that provides a good seedbed, drainage and water control.
- Contact your county Extension office for water quality testing if there is no recent history.
- Use multiple inlet irrigation on fields to improve water management and adjust levee gates to hold rainwater and act as overflow when levees are full.
- Be certain of accurate levee survey, proper levee construction and correct gate installation.
- Survey levees on 0.2-foot intervals when possible.
- Establish a levee base as early as possible (before seeding) on clay soils.
- Where choices exist, attempt to seed longer-season cultivars on fields with good water-holding capacity.
- Service and check out the pumping plant before the pumping season to prevent costly pumping delays and in-season repairs.
- Carefully analyze differences in energy costs. Select and use another energy source where economically justified. Use a meter in conjunction with electric and fuel bills to determine the cost of water for each pump. Use this information to service pumps or make changes to pumping plants.
- Choose the electric rate structure best suited for specific pumping situations. Cost savings are available for irrigation systems that can withstand peak load shutdowns (two to five hours per day).
- Work with equipment dealers on proper pump bowl selection, motor matching and operation of pumping plants. Improper pump selection and power unit selection can increase pump costs by two to three times. New pump installations should be within 80 percent of the Nebraska Pump Standards.
- Consider use of timers or pump control technology to manage irrigation pumps. Pump monitors are available to control pumps and document pump performance.
- Use a flow meter to measure water use. Using more than 19 inches on zero-grade fields and 32 inches on contour and straight levees may indicate a problem.
- Replace ditch and canal water delivery systems with pipe or tubing when possible.
- Flush if necessary for stand establishment or weed control.
- Maintain a shallow flood of 2 to 4 inches from beginning tillering until two weeks prior to harvest. For cultivars susceptible to rice blast disease, flood to a depth of 4 to 6 inches after midseason. Consider ceasing pumping on the field in preparation for harvest 14 days after heading if there is an adequate flood on the field to prevent drought stress during grain fill.
- Drain or allow to dry down if necessary for straighthead, scum or possible rice water weevil control.
- Aim to operate irrigation system so that no water leaves the field during pumping events and small rain events.
- Consider the use or conversion to surface water for irrigation. A decrease in pumping cost may be realized.

Critical Water Management Situations

Situation	Rice Stage	Recommended Practice or Precautions
After dry-seeding, no moisture for germination.	Rice not germinated.	Flush as quickly as possible, being sure surface water does not stand for more than 2 days. Use multiple water inlets if possible to reduce flush time.
Soil surface is crusted.	Rice germinated but not emerged.	Flush to soften crust before rice emerges or lose their penetrating power.
Residual herbicides have been applied, soil surface has become dry, weeds are germinating.	Rice has germinated and may be emerged.	Flush to activate herbicides.
Barnyardgrass has become drought stressed and is less than 4-leaf.	Rice may or may not be emerged.	Flush and apply herbicide before grass gets too large.
Barnyardgrass has become drought stressed and is less than 4-leaf.	Rice may or may not be emerged.	Flush and apply herbicide before grass gets too large.
Barnyardgrass has become too large, drought stressed or was not controlled.	Rice is 6" to 8" tall.	Flood, treat with Clincher, Ricestar or Regiment and maintain flood.
Seedling rice has tipburn and dying before flooding (salinity injury).	Rice has emerged but may be less than 8" tall.	Dilute the salts by flushing and don't let soil surface dry.
Rice has turned chlorotic within 2 to 4 days after flooding (high pH, Zn deficiency).	Rice is 6" to 10" tall.	Drain immediately, apply zinc and, after recovery, add N; reflood to shallow depth.
History of straighthead.	Rice is about 2 to 3 weeks prior to internode movement. (Consider DD50 drying time frame.)	Drain before DD50 first drying date to allow the soil to dry thoroughly until rice plants are drought stressed; then reflood, preferably before ½-inch internode elongation.
Not enough water; severe drought stress.	Rice can be in various stages.	Flush over quickly, then close gates and raise flood to desired depth as water becomes available.
Nitrogen applied on dry soil.	Rice is 3 weeks old.	Flood as soon as possible but within 7 days to place N below soil surface.
Nitrogen applied into flood.	Rice is at internode elongation.	Prefer flood to be low with little water movement. Delay pumping for 24 hours after N application.
Sprangletop or large barnyardgrass.	Rice is tillering to internode elongation (IE) stage.	Apply Clincher into floodwater. Flood must be maintained for suppression.
Drought, pumping flow rate is low.	Rice near heading.	Use multiple inlets; clean out algae in flow pattern to ensure sufficient water as heads emerge.
Preparation for harvest	Rice is about 10 to 14 days after heading; heads beginning to drop and some heads beginning to ripen.	Consider ceasing pumping on field in preparation for harvest 10 to 14 days after heading if there is an adequate flood on the field that would prevent drought stress during grain fill. However, if temperatures are exceedingly hot, then continue pumping 5 to 7 days.

Acknowledgement

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Chapter 11

Management of Rice Diseases

Yeshi Wamishe, Rick Cartwright and Fleet Lee

Despite advances in rice production technology, diseases remain a major cause of yield loss and lower profits on Arkansas rice farms. Diseases reduce yield and quality and increase production costs.

Disease impact on Arkansas rice production has increased over time. Use of high-yielding cultivars with less overall disease resistance and greater nitrogen (N) fertilizer requirements has increased rice yields but has also increased disease incidence. Rice is also now grown in shorter rotations, or no rotations, on increasingly less fertile soils and with decreasing irrigation capacity – all contributors to more severe disease.

The development of plant disease (epidemics) is governed by three factors over time, illustrated by the "Plant Disease Triangle"(Figure 11-1). These factors – susceptible cultivar, virulent pathogen and favorable environment – result in severe disease epidemics if all factors are present for a substantial period of time. If one of the factors is not present or if not all three are maintained long enough, then disease will be less severe or nonexistent.

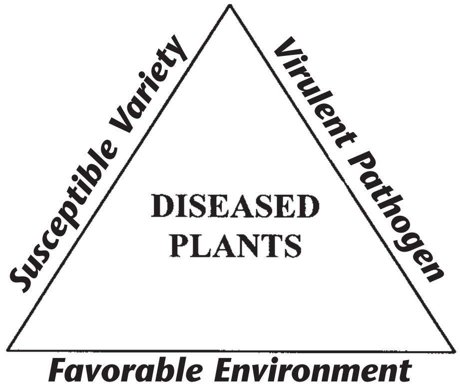


Figure 11-1. The Disease Triangle.

An example in rice is where a producer plants Francis (blast-susceptible variety) late in the spring in a field with a history of blast. Frequent light rains are experienced in June and early July, and the blast fungus (virulent pathogen) attacks the leaves, causing leaf blast. During the boot to early heading stages, the grower is unable to - maintain a deep (4 inches or greater) flood due to inadequate pumping capacity and/or poor water-holding capacity of the soil (blast-favorable stress on the plants). Frequent light rains return during this critical period, and temperatures are warm in the day and mild at night, resulting in heavy, extended dew when not raining (additional favorable environment). The result is a neck blast epidemic during heading and early grain fill and up to 80 percent yield loss (Photo 11-1).

Photo 11-1. Severe neck blast leads to blank panicles.

On the other hand, if hot, dry weather was present during the booting stage and/or if N application was not excessive and a deep flood maintained after mid-season, the same field suffers little yield loss from neck blast. This is because the environment was not favorable for spore infection and plants were more field-resistant to neck blast during the time when the cultivar was most susceptible (panicle emergence). Blast still remains an economically important disease when conditions are favorable (Photos 11-2a and 11-2b).

Photo 11-2a. **Severe leaf blast lesions on blast-susceptible cultivar in 2015.**

Photo 11-2b. Severe leaf blast causing plant death in 2014.

Sheath Blight

Sheath blight has been the most important rice disease in Arkansas and in the southern United States. Sheath blight is present in nearly every Arkansas rice field and causes a consistent level of damage each year. The disease is caused by a fungus called *Rhizoctonia solani* AG1-1A. Other crops grown in rotation with rice, including soybeans (Photo 11-3), corn, grain sorghum and various weedy grasses, also serve as host plants for the fungus – but rice and soybeans are most often damaged.

Photo 11-3. **Aerial blight of soybean symptoms caused by the sheath blight fungus of rice.**

The fungus survives between crops as "sclerotia" – hard, brown structures ⅛ inch or more in diameter that can lie dormant in the soil for at least two to three years (Photos 11-2 and 11-3). The fungus can also survive in infected rice straw or other crop residue but does not survive as long. In rice, the sclerotia (or infected debris) float out of the soil and may be moved around the field with irrigation water, rainfall or soil work. After the permanent flood is established, sclerotia infect the rice sheath at or just above the waterline in the late tillering to early reproductive growth stages. Sheath blight causes long, oval, purple-bordered lesions (spots) on infected sheaths (Photo 11-4) and bands of dying tissue in the leaf blades as it grows up infected plants (Photo 11-5). It spreads throughout the rice tissue by microscopic threads called hyphae and can grow at least an inch a day (24 hours) under favorable conditions. The fungus forms sclerotia on dying or dead tissue during the latter half of the rice-growing season. Sclerotia fall off the straw before or during rice harvest, assuring continued survival of the fungus in the field. Other sheath diseases are often confused with sheath blight, and careful identification is necessary to avoid unnecessary fungicide applications (Figure 11-2) (See Figure 11-3 for the disease cycle of sheath blight.)

Photo 11-4. **Young sheath blight lesions 10 days past ½" internode elongation.**

Photo 11-5. **Sheath blight damage later in the season with lesions and sclerotia.**

Conditions that encourage sheath blight include short, leafy rice cultivars (e.g., CL161 and Cocodrie); high N rates (>150 pounds N per acre) and hot, humid weather with temperatures between 80° to 92°F during

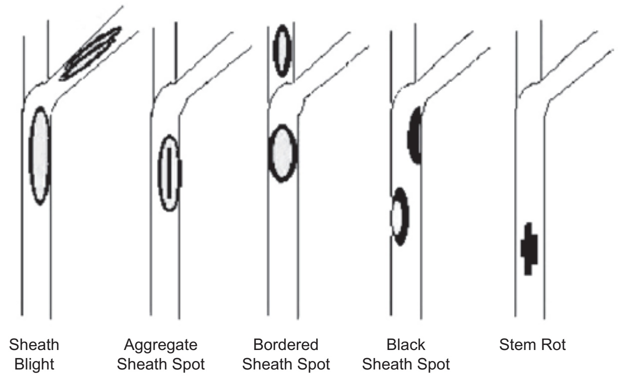


Figure 11-2. Early lesion types for various sheath diseases of rice – at or shortly after mid-season.

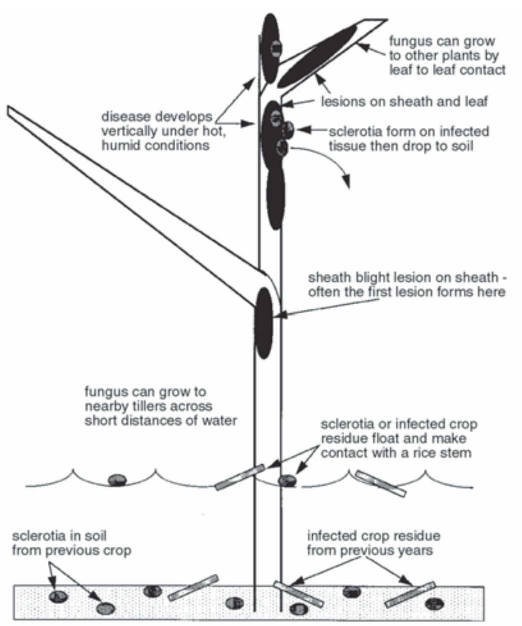


Figure 11-3. Disease cycle of sheath blight of rice.

the day and 74°F and above at night. Either hot, dry weather or cool temperatures can dramatically reduce the incidence and severity of sheath blight. Significant yield and grain quality losses result from widespread death of leaves in the mid to upper canopy prior to completion of grain fill or (rarely) direct infection of emerging panicles. Yield losses can reach 50 percent in heavily damaged areas of fields with highly susceptible semi-dwarf cultivars. However, yield losses of 5 to 30 bushels per acre are more common in "bad sheath blight" fields, depending on the cultivar. Quality (milling) losses of 1 to 3 percent of head rice have been documented in areas of fields where sheath blight reached the top two leaves prior to heading. Milling quality losses are less from sheath blight than from severe neck blast or kernel smut.

Management

- Plant less susceptible cultivars (Table 11-1), on fields with a history of sheath blight.
- Avoid thick stands; use a seeding rate that results in no more than 15 to 20 plants per square foot.
- Use no more than the recommended N rate for the field and cultivar, especially at the preflood N timing. Research has shown that excessive N rates at preflood increase sheath blight activity.
- Scout fields from panicle initiation (Figure 11-4) to 50 percent heading. While scouting methods vary, remember that sheath blight is often a problem only in certain fields or parts of a field (Photo 11-7). Growers can lose money applying fungicides to fields or field areas that do not have a sheath blight problem.

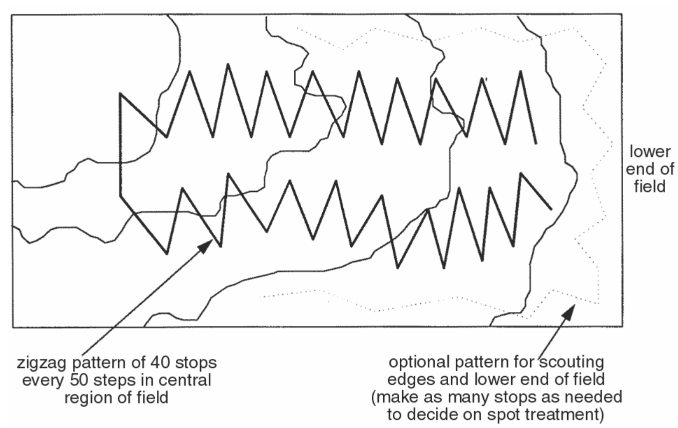


Figure 11-4. Recommended scouting pattern for sheath blight in a rice field.

Photo 11-6. Sclerotia of the sheath blight fungus on rice late in the season.

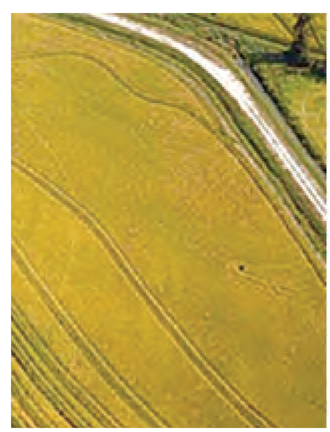


Photo 11-7. Patchy nature of sheath blight in the lower part of an Arkansas rice field. Light spots are small patches of sheath blight about three feet across.

- Use available effective fungicide if sheath blight is widespread in the field and threatening the upper two to three leaves before 50 percent heading. See Table 11-2 for sheath blight treatment thresholds and Table 11-3 for fungicide recommendations.

Table 11-1. Rice cultivar reactions to diseases, 2017.

Cultivar	Sheath Blight	Blast	Straight head	Bacterial Panicle Blight	Narrow Brown Leaf Spot	Stem Rot	Kernel Smut	False Smut	Lodging	Black Sheath Rot	Sheath Spot
CHENIERE	S	MS	VS	MS	S	S	S	S	MR	MS	--
CL111	VS	MS	S	VS	S	VS	S	S	MS	S	MS
CL151	S	VS	VS	VS	S	VS	S	S	S	S	MS
CL153	S	MS	--	MS	S	--	S	S	MR	--	MS
CL163	VS	S	--	MS	R	--	MS	--	MS	--	MS
CL172	MS	MS	--	MS	S	--	MS	S	MR	--	--
CL272	S	MS	--	VS	S	--	MS	--	MR	S	MS
COCODRIE	S	S	VS	S	S	VS	S	S	MR	S	--
DELLA-2	S	R	--	MS	MS	--	--	--	--	--	--
DIAMOND	S	S	--	MS	--	S	S	VS	MS	--	S
JAZZMAN-2	S	MS	--	VS	S	--	S	S	--	--	--
JUPITER	S	S	S	MR	MR	VS	MS	MS	S	MR	--
LAKAST	MS	S	MS	MS	MS	S	S	S	MS	MS	S
MM14	--	--	--	S	--	--	--	S	--	--	--
PVL01	S	S	-	S	-	-	-	VS	-	-	-
ROY J	MS	S	S	S	R	S	VS	S	MR	MS	MS
RT 7311 CL	MS	R	-	-	-	-	S	S	MS	-	-
RT CL XL729	MS	R	MS	MR	R	S	MS	S	S	S	--
RT CL XL745	S	R	R	MR	R	S	S	S	S	S	--
RTGemini214 CL	S	R	-	-	-	-	MS	VS	MS	-	MS
RT XP753	MS	R	MS	MR	R	--	MS	S	MS	S	--
RT XP760	MS	MR	--	MR	R	--	MS	VS	S	--	--
TAGGART	MS	MS	R	MS	MS	S	S	S	MS	MS	--
THAD	S	S	S	MS	-	-	S	VS	MR	-	MS
TITAN	S	MS	-	MS	-	-	MS	MS	MS	-	-
WELLS	S	S	S	S	S	VS	S	S	MS	MS	-

Reaction: R = Resistant; MR = Moderately Resistant; MS = Moderately Susceptible; S = Susceptible; VS = Very Susceptible (cells with no values indicate no definitive Arkansas disease rating information is available at this time). Reactions were determined based on historical and recent observations from test plots and in grower fields across Arkansas and other rice states in southern USA. In general, these ratings represent expected cultivar reactions to disease under conditions that most favor severe disease development.

Table prepared by Y. Wamishe, Assistant Professor/Extension Plant Pathologist.

Table 11-2. **Sheath blight treatment thresholds.**

Cultivar Reaction	Treatment Threshold (See Comments)		Comments
	Percent Positive Stops	Percent Infected Tillers	
VS	35	5-10	Scout early, starting at PI and be prepared to treat as soon as canopy closes or shortly thereafter, but before upper leaves are infected.
S	35	5-10	Start scouting about mid-season (PD) and treat when positive stop threshold is reached AND when the upper canopy is being threatened (often early boot).
MS	50	10-15	Scout from 7 days after midseason (PD) to 50% heading. Treat when positive stop threshold is reached AND the upper 2-3 leaves are being threatened (often mid to late booting).
MR			Spraying is not usually warranted.
VS = very susceptible; MS = moderately susceptible; MR = moderately resistant			
SCOUTING: The entire field should be scouted for symptoms in a zigzag pattern stopping every 50 steps (Figure 11-3). Only a 3-ft long section of rice should be inspected at each stop for sheath blight symptoms. If symptoms are present the stop is positive. A minimum of 50 stops per field should be made or one per acre to determine the level of sheath blight for the field. If sheath blight is not widespread in the field but concentrated in certain areas, then treating only those areas with the fungicide may be more economical. While experience may be substituted for scouting in fields with a history of sheath blight, the economic use of fungicides depend on adequate knowledge of the distribution of the disease in a field and its intensity between ½" internode elongation and early heading.			

Table 11-3. **Fungicides recommended for rice sheath blight, kernel smut and false smut control/suppression.**

Disease	Fungicide	Active Ingredient	Rate/Acre	Comments[1]
Fungicides to control sheath blight should be applied when effective scouting indicates more than 35% positive stops in susceptible to very susceptible varieties or more than 50% positive stops in moderately susceptible varieties between panicle differentiation and early heading. Maximum benefit from a single fungicide application will be achieved when made before the disease has damaged the upper 3 leaves of the canopy.				
Sheath Blight	Quadris 2.08 SC	azoxystrobin	8.5 - 12.5 fl oz	Lower rates may not provide adequate control under some conditions. Do not apply near fishponds or apple orchards. Read and follow label application directions carefully. Use higher rates or two applications for severe sheath blight conditions on highly susceptible varieties – SEE LABEL FOR RESTRICTIONS.
	Stratego	trifloxystrobin + propiconazole	16 - 19 fl oz	
	Quilt Xcel 2.2 EC	azoxystrobin + propiconazole	14 - 27 fl oz	Tested rates for Quilt Xcel were 17.5 fl oz (contains about 10 fl oz Quadris and 5 fl oz Tilt) and 21 fl oz (contains 12 fl oz Quadris and 6 fl oz Tilt) in Arkansas.
	GEM	trifloxystrobin	3.8 - 4.7 fl oz	SEE LABEL FOR RESTRICTIONS AND DIRECTIONS.
	Sercadis	fluxapyroxad	4.5 - 6.8 fl oz	SEE LABEL FOR RESTRICTIONS AND DIRECTIONS.
	Elegia	flutolanil	32 fl oz	SEE LABEL FOR RESTRICTIONS AND DIRECTIONS.
	Artisan	flutolanil + propiconazole	40 fl oz	SEE LABEL FOR RESTRICTIONS AND DIRECTIONS.
Kernel Smut and False Smut	Tilt 3.6 EC	propiconazole	6 fl oz	Apply at early to late boot but before heading begins as a preventive treatment for kernel smut and/or to suppress false smut. Propiconazole fungicides can be tank-mixed with certain sheath blight fungicides or follow them as needed. Fields most likely to benefit will be those planted to a susceptible variety and fertilized heavily with nitrogen. SEE LABEL FOR RESTRICTIONS AND DIRECTIONS.
	Propimax	propiconazole	6 fl oz	
	Stratego	trifloxystrobin + propiconazole	19 fl oz	
	Quilt Xcel 2.2 EC	azoxystrobin + propiconazole	15.75 - 27 fl oz	

[1] Assumes proper application and typical weather. Adverse conditions may decrease the performance of fungicides. Fungicide performance is greatly enhanced when plants are grown using proper cultural practices including maintaining continuous deep flood (especially after the very early boot stage of growth) and use of recommended N rates for the variety. Proper cultural practices greatly enhance the field resistance of rice cultivars.

Disclaimer: The mention of proprietary products does not constitute an exclusive endorsement of their use and the label should always be consulted prior to use. Changes in labels and use recommendations often occur yearly, so you should consult the county extension agent or other knowledgeable person each year for the latest fungicide information.

Blast

Blast is an unpredictable disease which can cause severe yield losses under favorable environmental conditions. An airborne fungus called *Pyricularia oryzae* causes blast and is a worldwide problem in rice production. The fungus survives between crops on infected rice straw or on seed (Photo 11-8). As far as is known, rice blast only infects rice. Other forms of the blast fungus may attack certain grassy weeds, but these forms are unable to affect rice. The fungus can infect leaves, collars, nodes and panicles of rice plants. Distinctive, airborne spores (Photo 11-9) spread the disease. The blast fungus exists as a number of races; that is, genetically distinct biological variants infect certain rice cultivars but not others. New races emerge from time to time, in response to the planting of particular resistant cultivars and may overcome this resistance. For example, Pi-ta resistance, originally found in Katy rice and used extensively in new varieties since 1989, can now be overcome by a race of the blast fungus known as IE-1k – first noted in 1994 and that has since caused field damage on certain cultivars considered resistant.

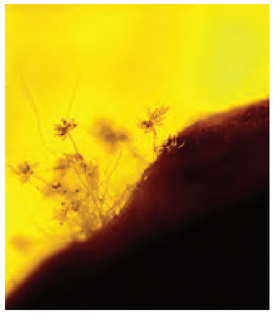


Photo 11-8. Rice blast fungus sporulating on surface of infected rice seed.

Photo 11-9. Spores of the rice blast fungus, highly magnified.

Photo 11-10. Leaf blast lesions on a blast-susceptible cultivar.

Blast lesions typically are spindle- to diamond-shaped spots on leaves. Lesion size varies from small to large depending upon plant susceptibility, with the most commonly observed field lesion having a reddish brown border and off-white to tan center (Photo 11-10). These lesions produce numerous airborne spores under favorable conditions. At heading, spores can infect the node below the panicle, resulting in "neck blast" (Photo 11-11) – the most damaging type of blast. (See Figure 11-5 for the disease cycle of rice blast disease.) Because blast spores need free moisture on the plant to cause infection, the disease is favored by long dew periods (9 plus hours) – increased by fog, shade or frequent light rains.

External Environmental Conditions

Blast is usually worse when temperatures are slightly cooler than those mentioned for sheath blight and in selected fields where environmental conditions promote long dew periods. Late seeding dates increase the likelihood of blast infection.

Photo 11-11. Neck blast symptoms on a blast-susceptible rice cultivar.

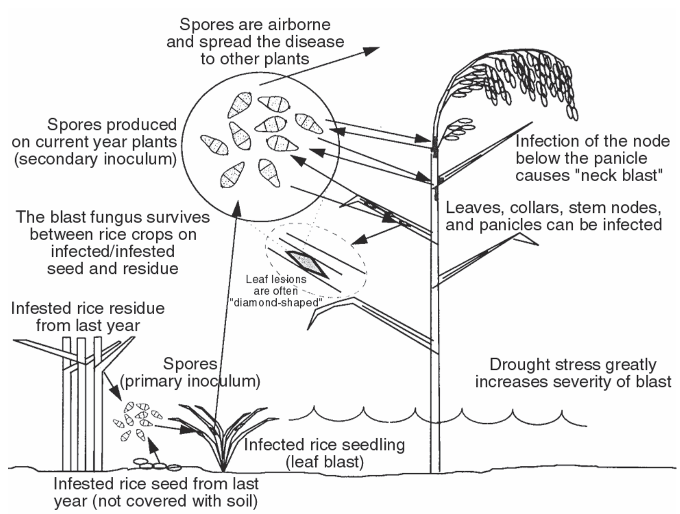


Figure 11-5. Disease cycle of rice blast disease.

Management

- Plant resistant cultivars, especially in fields with a history of blast or difficult to irrigate – but keep in mind that all cultivars may become susceptible over the years, should the fungus adapt and overcome the resistance in a particular cultivar – so all cultivars should be spot-checked for symptoms.
- Use clean, fungicide-treated seed.
- Plant early (April) to avoid the likelihood of heavy blast pressure late in the season.
- Use the recommended N fertilizer rate. Avoid high N rates or high organic matter soils, especially with susceptible cultivars in blast-prone fields.

- Maintain a consistent, deep flood (≥ 4 inches), especially after the drain and dry period for straighthead prevention. Avoid losing the flood or shallow floods, especially on susceptible cultivars.
- Periodically scout fields for leaf blast symptoms on all cultivars, even cultivars considered resistant. The best time to scout has historically been during June as leaf lesions tend to disappear once the plants enter the booting stages. If leaf blast is detected, increase the flood depth in the field for the rest of the season and prepare for preventative fungicide applications at early heading (Figure 11-6). See Table 11-4 for blast fungicide guidelines. Fungicides are not 100 percent effective but can limit lesion spore production and infection if combined with proper flooding practices.

For reasons not fully understood, several cultural practices greatly impact plant metabolic processes associated with blast resistance. High organic matter soils and/or use of high N rates increase susceptibility. Plants grown under consistent, deeper irrigation floods (≥ 4 inches) are much less susceptible to blast than plants that are grown under more shallow floods, moist soil or drought-stressed conditions (Figure 11-7). This flood response, which impacts

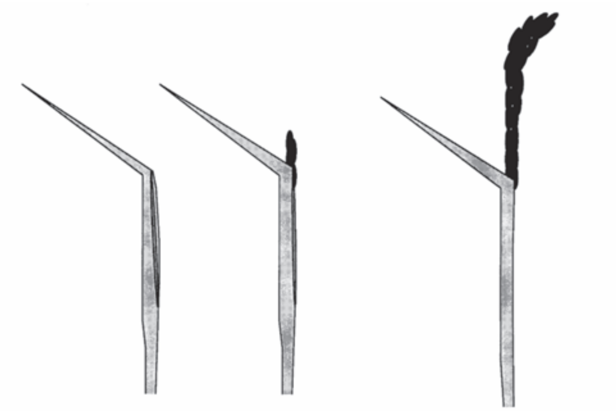
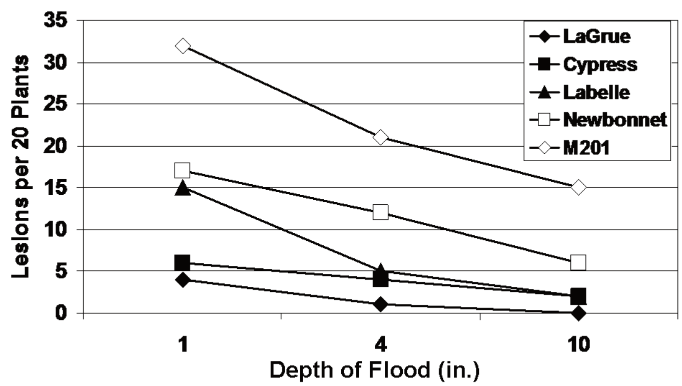


Figure 11-6. Growth stages of rice for proper application of fungicides to control neck blast.



Source: Lee et al. 1996. p. 139-144. *B.R. Wells Rice Res. Studies 1995.* Ark. Agr. Exp. Sta. Res. Ser.

Figure 11-7. Influence of flood depth on rice blast lesion development in five rice cultivars.

Table 11-4. Fungicides recommended for use in management of rice blast disease.

Disease	Fungicide	Active Ingredient	Rate/Acre†	Comments[1]
Neck Blast[2] (susceptible varieties – see notes and comments)	Quadris 2.08 SC	azoxystrobin	12.5 fl oz	Keep permanent flood depth of at least 4 inches to suppress early leaf blast and neck blast. Fungicides for neck blast work best if applied twice, the 1st at late boot and the 2nd when panicles of the main tillers are 50%-75% heading but when the neck is still in boot. SEE LABELS FOR RESTRICTIONS AND DIRECTIONS.
	GEM	trifloxystrobin	3.1 - 4.7 fl oz	
	Stratego	trifloxystrobin + propiconazole	19 fl oz	
	Quilt Xcel 2.2 EC	azoxystrobin + propiconazole	21-27 fl oz	

[1] Assumes proper application and typical weather. Adverse conditions may decrease the performance of fungicides. Fungicide performance is greatly enhanced when plants are grown using proper cultural practices including maintaining continuous deep flood (especially after the very early boot stage of growth) and use of recommended N rates for the variety. Proper cultural practices greatly enhance the field resistance of rice cultivars.

[2] No thresholds have been developed for blast. The presence of leaf, collar and/or neck lesions in the field or nearby fields of susceptible varieties triggers consideration of a fungicide treatment. Water management and flood depth greatly influence the development of blast. Refer to the latest variety ratings available through the county Extension office for further information. All varieties should be inspected occasionally prior to heading as the blast fungus can adapt and attack resistant varieties.

NOTE ON FUNGICIDES AND OTHER RICE DISEASES: We do not currently recommend fungicides for control of other rice diseases in Arkansas. Current fungicides used in rice are not recommended for bacterial panicle blight. Please consult the latest fungicide label for information on control of other rice diseases if deemed necessary.

Disclaimer: The mention of proprietary products does not constitute an exclusive endorsement of their use and the label should always be consulted prior to use. Changes in labels and use recommendations often occur yearly, so you should consult the county extension agent or other knowledgeable person each year for the latest fungicide information.

infection, lesion development and sporulation, is better manifested in poorly drained soils than in soils with an excessive internal percolation.

Stem Rot

Stem rot is a historically important rice disease in Arkansas and has recently become more so due to low levels of available potassium (K) in our silt and sandy loam rice soils. Fields with severe stem rot usually have low soil test K as a result of inadequate K fertilization.

Stem rot is caused by the fungus *Sclerotium oryzae*, which survives in the soil between crops as long-lived, tiny, black sclerotia. Like sheath blight, sclerotia of the stem rot fungus are moved around with soil and water. Sclerotia float on the surface of flood water, contact a rice stem and infect the sheath, causing a small, black, blocky lesion at or just above the water line (Photo 11-12). After sheath infection, stem rot grows primarily inward. If the fungus reaches the culm before grain fill is completed, the tiller dies, resulting in partially filled or blanked grains (Photo 11-13).

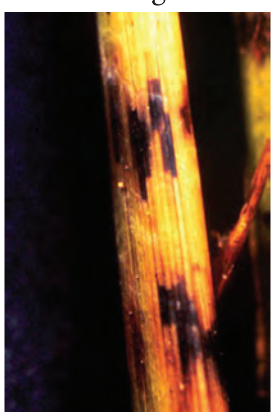


Photo 11-12. **Stem rot lesion on rice.**

Stem rot has been documented to cause up to 70 percent yield losses and 100 percent lodging in fields with severe disease (Photo 11-14). While slower to develop than sheath blight, stem rot can move rapidly into plants that have high levels of N or low levels of K in sheath and stem tissue. A tissue N:K ratio of 3:1 and above after mid-season strongly favors severe stem rot. All current cultivars of rice are susceptible to stem rot when grown on soils deficient in K.

Photo 11-13. Severe stem rot of rice (left) versus healthy rice stem (right). Photo taken during late grain fill period.

Management

- Soil sample on a regular basis (preferably in February before each rice crop), especially for silt and sandy loam soils.
- Apply K fertilizer as recommended by the soil test. On soils where salt injury to seedlings is a concern, K fertilizer can be applied immediately before or after flooding when plants are more mature and stable.
- Use the recommended rate of N fertilizer. Avoid excessive N rates.

Photo 11-14. Field of rice severely infected by stem rot. Rice was deficient in potassium.

Crown (Black) Sheath Rot

Crown sheath rot is a common sheath disease in Arkansas rice fields, especially where rice has not been planted on a consistent basis or on new rice fields. Once sheath blight and stem rot become common, black sheath rot is less noticed. Black sheath rot is caused by the fungus *Gaeumannomyces graminis* var. *graminis* and survives between crops on other grasses and infected rice straw.

The disease cycle on rice is not well understood, but symptoms are usually first noticed on sheaths from the green ring to ½ inch internode elongation (midseason) stages. A grayish-black to dark brown/black lesion up to 1 inch long and irregular in shape usually forms on the sheath just above the waterline (Photo 11-15). The inner part of the lesion is often lighter in color and has off-white to greenish-gray color. A distinguishing characteristic of the black sheath rot fungus is

Photo 11-15. Early crown (black) sheath rot of rice symptoms. Note irregular shape of gray-black lesions with lighter interiors.

the production of fan-shaped strands of dark brown hyphae called a mycelial mat that develops under the sheath (Photo 11-16). The mycelial mat can be observed on the underside of infected sheaths with a hand lens. Later symptoms include rotted sheaths and numerous black dots within older lesions (Photo 11-17). The black dots are tiny beaked spheres containing spores of the fungus (Photo 11-18). While yield losses up to 20 percent have been measured in inoculated research plots, losses in commercial fields are usually minor. Heavier yield loss may occur on highly susceptible varieties that have been overfertilized with N, planted extremely thick or grown on new rice fields.

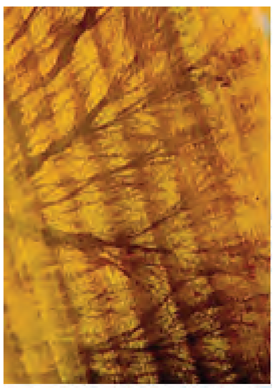


Photo 11-16. Mycelial mat of the black sheath rot fungus magnified with a hand lens. This is an identifying characteristic for this disease and can often be found on the underside of the infected sheath.

Photo 11-17. Rotted sheaths containing tiny black specks caused by black sheath rot later in the season.

Photo 11-18. Highly magnified view of one of the black specks from Photo 11-17 – perithecium of the black sheath rot fungus.

Management

- Plant a less susceptible cultivar in fields with a consistent history.
- Use a seeding rate that results in 15 to 20 plants per square foot. Avoid thick stands.
- Use only the recommended N fertilizer rate. Avoid excessive N rates.
- Fungicides at higher rates and earlier timings have provided some control of the disease but are generally not needed.

Kernel Smut

Kernel smut or black smut of rice became increasingly important during the 1990s. It has been considered an emerging disease since 2010. Yield losses of 10 to 30 percent have been measured on highly susceptible cultivars on occasion. Head rice yield losses of more than 6 points have been documented in severe cases. Smutted rice is undesirable for parboiling because it turns parboiled rice gray.

The kernel smut fungus is currently known as *Neovossia horrida* or *Tilletia barclayana*. The fungus survives as tough, microscopic black teliospores that replace the rice kernel during grain fill (Photos 11-19 and 11-20). The spores are extremely common in Arkansas rice areas, found in soil, equipment and water. The spores can literally be found in every field where rice has been grown.

Like stem rot, the spores of the kernel smut fungus float on water. Kernel smut spores germinate on the water surface and expel other spores (sporidia) into

Photo 11-19. Kernel smut on heavily fertilized rice.

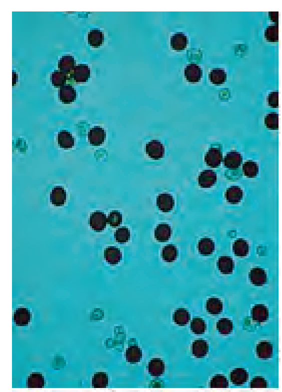


Photo 11-20. Heavily magnified spores of the kernel smut of rice fungus. These spores survive in the soil.

the air. The sporidia enter the flowers, infect and eventually replace the endosperm of the rice kernel with numerous black teliospores. During grain fill, alternate wetting and drying of the infected grain results in kernel rupture and release of the teliospores. Combines used to harvest heavily smutted fields often have a black, sooty coating of kernel smut spores (Photo 11-21).

Photo 11-21. **Combine harvester covered with spores of the kernel smut fungus in a heavily diseased rice field.**

Management

- Plant less susceptible cultivars in fields with a history of severe kernel smut (Table 11-1).
- Use only the recommended rate of N fertilizer. Avoid excessive N rates, especially at the preflood timing.
- Apply a fungicide containing propiconazole at the labeled rate and timing (booting stages preferred) to minimize kernel smut in fields seeded with a susceptible cultivar and that have had historical smut problems (Table 11-3).

False Smut

False smut disease, also known as orange or green smut, was first reported in Arkansas during 1997 but has been reported elsewhere in the United States for some time. False smut caused widespread concern in 1998, especially in northeast Arkansas, when environmental conditions apparently favored disease development. False smut is caused by the fungus *Ustilaginoidea virens* and survives in the soil or in contaminated rice grain as spore balls (galls). False smut results in the replacement of the rice kernel with an unsightly gall or in blanking of kernels under certain conditions.

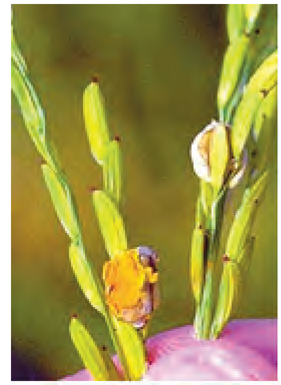


Photo 11-22. **Very young spore balls of the false smut of rice fungus – note silvery white covering.**

Galls rapidly develop within the infected kernel, emerging from between the glumes first as a silvery-white structure (Photo 11-22). When mature, the spore balls are ¼ to ½ inch in diameter and appear bright orange but later darken to olive-green or brown (Photo 11-23). When disturbed, the mature spore balls release tiny airborne spores that appear as orange dust. These spores likely infect later panicles, continuing the disease cycle late into the grain-fill season.

Factors that delay maturity seem to encourage false smut. For this reason, levees, herbicide-damaged areas, replanted areas and other problem spots may have a higher incidence of false smut than the rest of the field. False smut is primarily a quality problem in rice and has not caused heavy yield losses to date. The presence of large numbers of spore balls in harvested rice (Photo 11-24) is of concern to seed dealers and grain processors, since the spore balls must be removed before use of the rough rice. False smut is also a problem for rice intended for export as importing countries may reject rice due to phytosanitary concerns.

Photo 11-23. **"Orange" spore ball stage of false smut. Uncountable microscopic spores are released during this stage and infect surrounding immature rice panicles.**

Photo 11-24. **Spore balls for false smut mixed with rice grain.**

Management

- Plant less susceptible cultivars in fields with false smut history (Table 11-1).
- Plant early, before May 10 if possible. Late May and June plantings usually have a greater incidence of false smut.
- Avoid high N rates as this greatly increases disease.

Fungicides containing propiconazole suppress false smut if applied from boot to boot split stages; however, control is not as effective as for kernel smut. Fungicides applied after boot split are only about one-half as effective as boot applications and these later applications are currently illegal.

Bacterial Panicle Blight

Bacterial panicle blight (panicle blight) is caused by the bacteria *Burkholderia glumae* and *B. gladioli*. The bacteria are known to cause seed and seedling rot. However, the panicle symptoms appear at heading without prior warning. During grain fill, depending on disease severity, clusters of panicles do not fill out and turn over because they are blanked (Photo 11-25). Color of the blanked grain is uniformly tan at first, but it later turns a grayish color as other micro-organisms invade. Sometimes there are aborted (tiny) kernels inside the hulls of affected grains. Also, there is often a large, reddish-brown lesion on the flag leaf sheath that may result in the death of the flag leaf (Photo 11-26).

Photo 11-25. Bacterial panicle blight on a very susceptible rice cultivar.

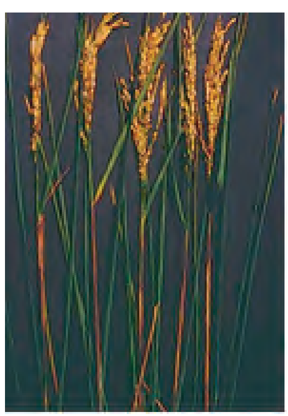


Photo 11-26. Brown flag sheath lesions of bacterial panicle blight that sometimes are observed, but not always.

Bacterial panicle blight has primarily been a problem on Bengal rice in Arkansas. This disease has been notably worse in very hot years like 1995, 1998 and 1999 in Arkansas, resulting in yield losses of up to 18 percent. However, in 2010 and 2011, the disease became widespread, causing yield losses up to 50 percent. *Burkholderia glumae* appeared to be the major bacterium and has been isolated from affected rice panicles and seed lots in Louisiana, Texas and Arkansas. The disease has likely been in the U.S. as an unidentified problem for many years. Conditions such as high night temperature, water stress, high nitrogen fertility, high seeding rate and late planting appeared to increase its incidence and severity. To date there are no labeled chemicals for use against bacterial panicle blight disease. Most of the commercial cultivars are susceptible to the disease (Table 11.1). Jupiter and some hybrid rice are moderately resistant.

Management

- Plant cultivars moderately resistant in areas where the disease has been consistent. A medium-grain variety, Jupiter, and some hybrids have shown some level of resistance in Louisiana and Arkansas field trials.
- Plant early (April) as late-planted rice has been more affected in the past.
- Avoid water stress (low) and excessive N rates.

Brown Spot

Brown spot is a historical rice disease that occasionally causes problems in Arkansas. The fungus *Bipolaris oryzae* (formerly *Helminthosporium oryzae*) causes brown spot. The fungus persists on infected rice seed and probably on infected crop debris. It has traditionally been a seedling disease problem under Arkansas growing conditions but can also attack the leaves and panicles of stressed rice plants. Rice suffering from N, K or P deficiency is especially susceptible to brown spot.

Photo 11-27. Highly magnified view of spores of the brown spot fungus.

The fungus has airborne spores (Photo 11-27) that infect the plant when free moisture is available. Infection causes oval-shaped lesions on rice leaves and grains. On resistant, healthy rice leaves, the spots are small and dark brown, staying less than ⅛ inch across (Photo 11-28). On susceptible cultivars or nutritionally deficient rice, the spots enlarge to ¼ inch or larger with a tan center and dark border (Photo 11-29) and may also damage the panicles (Photo 11-30). Brown spot lesions are occasionally confused with leaf blast lesions.

Photo 11-28. Typical brown spot leaf lesions on healthy rice.

Photo 11-29. Severe brown spot leaf lesions on potassium-deficient rice.

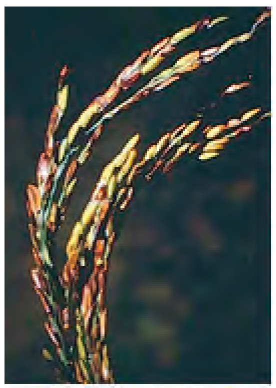


Photo 11-30. Severe brown spot disease of potassium-deficient rice panicle during 1994.

Management

- Plant cultivars that are resistant to brown spot.
- Use clean, fungicide-treated seed.
- Routinely sample and test soil for nutrients and apply the recommended fertilizers, especially K.
- Use the recommended rate and timing for N fertilization.
- Fungicides are not recommended for brown spot control, although several have activity against the fungus. On most cultivars, severe brown spot indicates a nutritional problem that fungicides cannot correct. Therefore, fungicide application to reduce disease incidence will not prevent yield reductions. Correction of the underlying nutritional problem(s) is essential for management of brown spot on rice.

Straighthead

Straighthead is a physiological disorder of unknown cause. Similar symptoms can be induced with arsenic under artificial conditions; however, various soils may result in straighthead symptoms. Straighthead is an old problem, usually on lighter textured rice soils of Arkansas. “Drain and dry” irrigation strategies currently used to control straighthead were developed by farmers in the early 1900s.

Symptoms are blanked or partially blanked panicles, often with some distorted (parrot-beaked) or only partially formed grains (Photo 11-31). **[Glyphosate (Roundup) herbicide drift on rice during reproductive growth stages can result in similarly distorted panicles, as well.]** In severe straighthead cases, the panicles may not emerge from the boot, and new tillers may emerge from nodes below the panicle. Affected plants may remain dark green through grain maturity in the field. Severely affected plants are often more common where the flood is deepest and most consistent, such as in barrow ditches. Although straighthead may be worse in some years than others, it generally reappears in the same fields or areas of fields each time rice is grown.

Photo 11-31. Straighthead of rice. Note the distortions (parrot-beaking) of the grains.

Management

- Plant less susceptible cultivars. Cocodrie, CL131, CL151, Cheniere and Mermentau are especially susceptible to straighthead, and water management for straighthead prevention is very difficult. Do not plant highly susceptible cultivars on fields with a history of straighthead.
- Drain the field to aerate the soil and roots according to the DD50 predicted time frame. Draining and drying of the soil must be thorough for maximum control but may increase the chances of blast disease later. For this reason, blast-resistant cultivars with good straighthead resistance should be considered for fields with severe straighthead histories.

- Fields with silt or sandy loam soils high in organic matter (i.e., freshly cleared ground) or a history of cotton production favor straighthead.

Autumn Decline or Akiochi

This is another physiological disorder of rice thought to be caused by hydrogen sulfide (H_2S) toxicity to rice roots grown in highly anaerobic flooded soils. Rice roots turn black and eventually die and rot, resulting in wilting, yellowing, stunting and sometimes death of the plant. Eventually, the crown rots internally (Photo 11-32) and adventitious roots develop from nodes in the flood water as plants try to survive the loss of the roots and crown. Traditionally, fields diagnosed with this disorder had very high levels of sulfate in the soil and irrigation water, and rotten egg odor (H_2S gas) was noticed. In recent years, other fields have shown symptoms, especially in cold water areas. A large quantity of undecomposed crop residues present at the time of flooding can increase the sulfur reduction process and aggravate this disorder.

Photo 11-32. Rice roots with autumn decline possibly caused by hydrogen sulfide toxicity compared to healthy roots.

Management

- Scouting of historical problematic fields should be conducted starting 10 days after permanent flood. For fields with known history of black root rotting problem, follow preventative strategy, i.e., "drain and dry," as is done for straighthead and at same timing. Once roots start to discolor, draining the field for aeration is the recommended option. The field does not have to be thoroughly dried. As soon as healthy, white roots appear, a shallow flood can be established. For fields with no history, follow rescue strategy. Drain to allow oxygen into the soil. Draining the flood can be risky late in the growing season, when symptoms are often noticed, due to the chance of possible blast infection or drought damage when water is limited. However, only a short time is needed for new root growth, which helps prevent or minimize potential blast or drought damage from flood removal.
- If the water is the source of sulfur, a different water source should be used. Have the water source tested if in doubt.
- Short-season rice cultivars may escape some damage and should be considered for fields with a history of this problem.

Narrow Brown Leaf Spot

Narrow brown leaf spot has been a minor, late-season disease of rice in Arkansas. Traditionally, it has little effect on yield or quality loss, but it caused problems late in 2006. Narrow brown leaf spot is caused by the fungus *Cercospora oryzae* and can infect leaves, sheaths and panicles. The fungus is airborne and probably survives between crops in residue and on seed.

Photo 11-33. Narrow brown leaf spot lesions on Kaybonnet rice.

Symptoms on leaves are usually first noticed as very narrow, reddish-brown lines (less than ¼ inch long) on the leaf (Photo 11-33). Later, the fungus invades the aging sheaths, forming netted reddish-brown discolored areas that may resemble the collar rot symptom of blast (Photo 11-34). Affected sheath lesions are irregularly shaped and can be several inches long. Lastly, the fungus can infect the node area just below the panicle or tissue just above the node, causing a dark brown discoloration

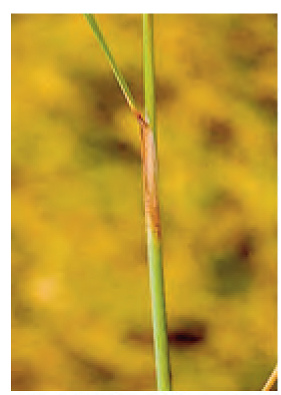


Photo 11-34. **Narrow brown leaf spot lesion on sheath of Kaybonnet rice late in the season.**

that appears similar to neck blast. Although their appearances are similar, blanking from narrow brown leaf spot is minimal, and the described symptoms usually develop only near the completion of grain fill. Some spikelets and individual flowers may be blanked by this disease, especially in no-till fields or in years with repeated light rainfall or other moisture during heading.

Management

- Where known, avoid highly susceptible cultivars (Table 11-1) if this disease becomes a consistent problem.
- Maintain a good fertility program based on routine soil testing.
- Plant early to escape late-season disease buildup.
- If a concern, fungicides containing propiconazole can be used during the booting stages to prevent or minimize this disease, according to the experience of Drs. Groth and Krausz of LSU and Texas A&M.

Other Minor Diseases

There are several other diseases of rice in Arkansas. None cause routine problems but may occasionally cause yield loss in specific circumstances or may be confused with more important diseases.

Bordered sheath spot, caused by the fungus *Rhizoctonia oryzae*, and **aggregate sheath spot**, caused by the fungus *Rhizoctonia oryzae-sativae*, are commonly found in Arkansas rice fields but do not cause yield losses on current cultivars. Sheath lesions caused by *R. oryzae* are similar to sheath blight lesions but usually stay only on the sheath, are smaller and more rounded and have a thick, dark brown border (Photo 11-35). Sheath lesions caused by *R. oryzae-sativae* are usually small and circular or long and oval but almost always have a thin, brown vertical line in the center of the lesion – especially if viewed when held up to the light (Photo 11-36). While these diseases alone are not important, both diseases have caused unnecessary fungicide applications for growers who believed the diseases to be sheath blight.

Photo 11-35. Bordered sheath spot of rice, sometimes confused with sheath blight lesions.

Leaf smut, caused by the fungus *Entyloma oryzae*, is often observed on the upper leaves of rice overfertilized with N. It is increased by the same factors that favor kernel smut, and often the two diseases are noticed on the same plants. Leaf smut symptoms include small, rectangular black spots on the leaves (Photo 11-37). Leaves with a large number of lesions may have a dark appearance. While fungicides are not recommended for control, leaf smut is very sensitive to propiconazole and has been used in the past to demonstrate fungicide activity in treated fields.

Sheath rot, caused by the fungus *Sarocladium oryzae*, is sometimes confused with sheath blight, a major rice disease in Arkansas. Under our growing conditions, sheath rot is almost always associated with panicles injured in the boot stage by insects, herbicides or other factors. Thus, affected plants are often found near the edges of fields. Affected panicles are blanked or partially blanked, and infected kernels turn a characteristic chocolate brown after the panicle emerges. Panicles that do not emerge from the boot often rot and have dark brown lesions on the flag leaf sheath (Photo 11-38).

Scab, caused by the fungus *Fusarium graminearum*, is the same disease as head scab of wheat. Individual grains or spikelets are typically infected

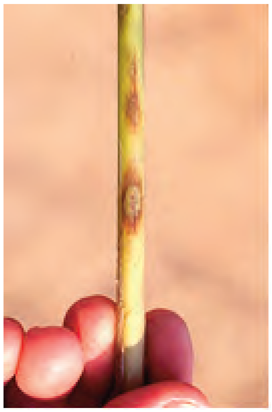


Photo 11-36. Aggregate sheath spot of rice. Note brown vertical line in the center of the lesion.

Photo 11-37. Leaf smut of rice. Note tiny black, rectangular leaf spots. Photo by M.C. McDaniels.

Photo 11-38. Sheath rot of rice, usually found around the edges of field or where rice has been injured.

and killed by the scab fungus, which produces bright orange spore masses on the dead grains (Photo 11-39).

Scald, caused by the fungus *Microdochium oryzae* (*Gerlachia oryzae*), can produce spores. The disease shows up occasionally in wet summers in Arkansas. The fungus invades the ends or sides of leaves, producing characteristic bands of discolored tissue, with different shades of brown (Photos 11-40 and 11-41).

While none of these minor diseases are of much concern now, as cultivars and cultural production practices change to increase yields and production efficiency, conditions may become favorable for these diseases to be more threatening.

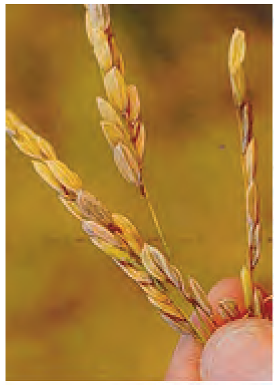


Photo 11-39. Head scab of rice – note the orange color on infected kernels (spore masses of the fungi) and the brown lesion at the base of the kernel.

Photo 11-40. Scale of rice.

Photo 11-41. Highly magnified view of spores of the scald of rice fungus.

Chapter

12

Insect Management in Rice

Gus Lorenz, Nick Bateman, Jarrod Hardke and Aaron Cato

Compared to other crops grown in the Mid-South, there are only a few insects considered to be important pests of rice. Insects may damage rice by feeding on the leaves, stems, roots or grain. This section contains a brief description of the pests of rice, the injury they cause, scouting procedures and control methods for the major and minor insect pests of rice. We have learned in recent years the impact that broad spectrum insecticide applications can have in disrupting the natural balance of insects in rice and recommend that foliar insecticide applications be considered only when insect numbers reach levels that may reduce rice yield and/or quality. Be reminded that many crop production practices directly influence insect populations. Use of best management practices can reduce insect pests and the need for insecticide applications. Some factors that can impact rice insect pest populations include:

Planting date can influence many insect pests. Very early- and late-planted rice is most vulnerable to rice stink bug infestation. If you plant earlier than surrounding growers, rice stink bugs will be attracted to the first fields that are heading, and numbers can be extremely high until surrounding fields begin to head and rice stink bugs disperse. The same is true for late-planted rice. If all the rice around you is mature and being harvested and you still have green rice, stink bugs will be attracted in high numbers to these fields. Late-planted rice is also susceptible to armyworms and stalk borers.

Rice stand has a significant impact on rice water weevils. Thinner stands usually have larger numbers of rice water weevil and subsequent damage than adequate stands. Thin stands are often associated with weed problems, particularly grass, which can attract rice stink bug. Thin stands can often be associated with chinch bug problems as well.

Weed control can also impact insect pest numbers. Grass weeds, particularly barnyardgrass, in and around rice fields are very attractive to rice stink bugs. Often rice stink bugs will stage around fields with heading barnyardgrass, as well as other grasses, and build up in number before moving into rice when it begins to head. Rice fields near pastures, sorghum, CRP, etc., are more susceptible to rice stink bug problems. Examination of these areas by rice fields should be made as an indication of potential problems before rice begins to head.

Fertilization can also play a role in insect problems. Overfertilization can attract insects, and growers can reduce exposure to insects as well as disease and lodging problems by proper fertilization.

Water management can be very helpful in controlling insect pests. One way to control armyworms and chinch bugs is with timely flushing or flooding of the field. Flooded rice is much less prone to armyworm damage. Flushing a field will push chinch bugs out of the soil and up to the plant where they can be reached with a foliar insecticide application. Rice water weevils can be controlled by pulling the flood and allowing the ground to crack, as the larvae must have saturated soil to survive. This method of control for weevils can be very effective.

These cultural practices can help growers manage insect pests, reduce the need for supplemental insecticides and help increase profitability.

Major Pests of Rice

Insects that are considered pests in rice include aboveground plant feeders, stem borers, stem and root feeders and panicle feeders. Figure 12-1 provides an overview of the growth stages when specific insects are likely to damage drill-seeded rice. In contrast, water-seeded rice presents a slightly different scenario, particularly during the early part of the season (Figure 12-2). It is important to understand when the plant is most heavily affected to ensure proper timing for scouting and control measures.

Grape Colaspis or Lespedeza Worm [*Colaspis brunnea* (F.)]

Description

Adults are golden-brown beetles about 3⁄16 inch in length but oval in overall shape (Photo 12-1). Larvae are white grubs about ¼ inch in length with a brown head and cervical shield (Photo 12-2). Larvae have three pairs of thoracic legs plus fleshy appendages bearing a few apical hairs on the abdominal segments. Grape colaspis larvae can be distinguished from other white grubs with use of a 10X lens by identification

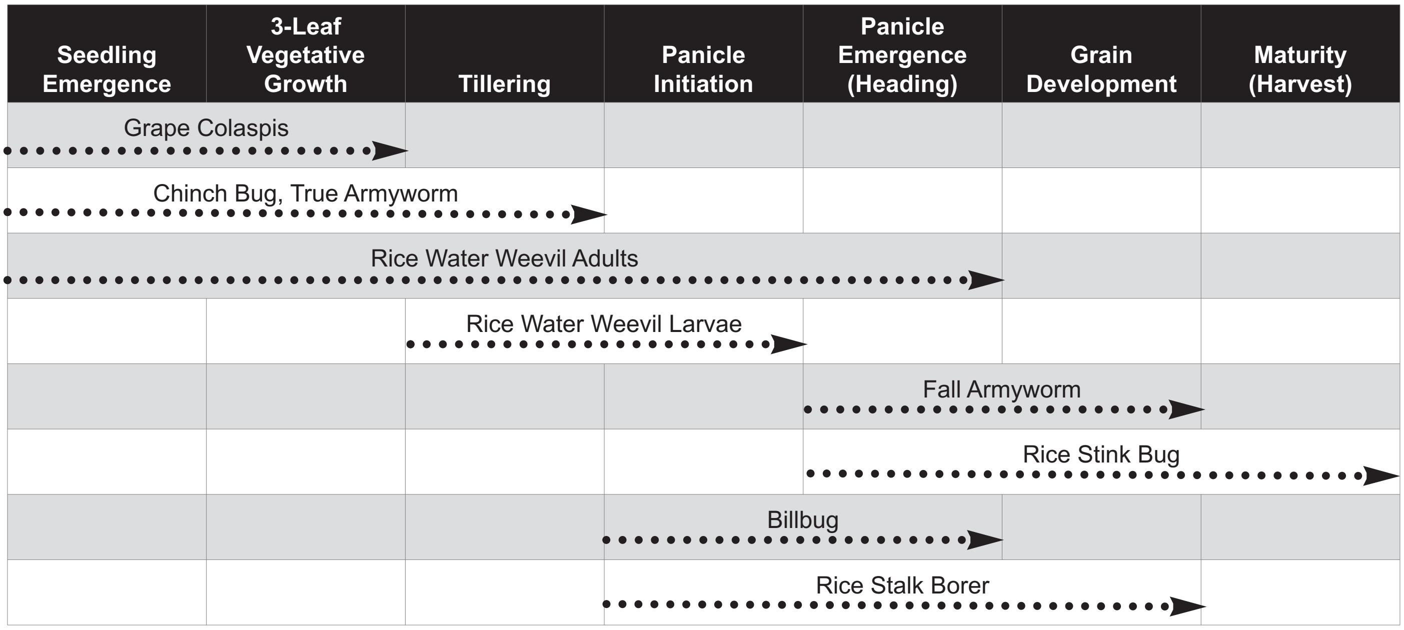


Figure 12-1. **Insects impacting drill-seeded rice and general growth stages affected.**

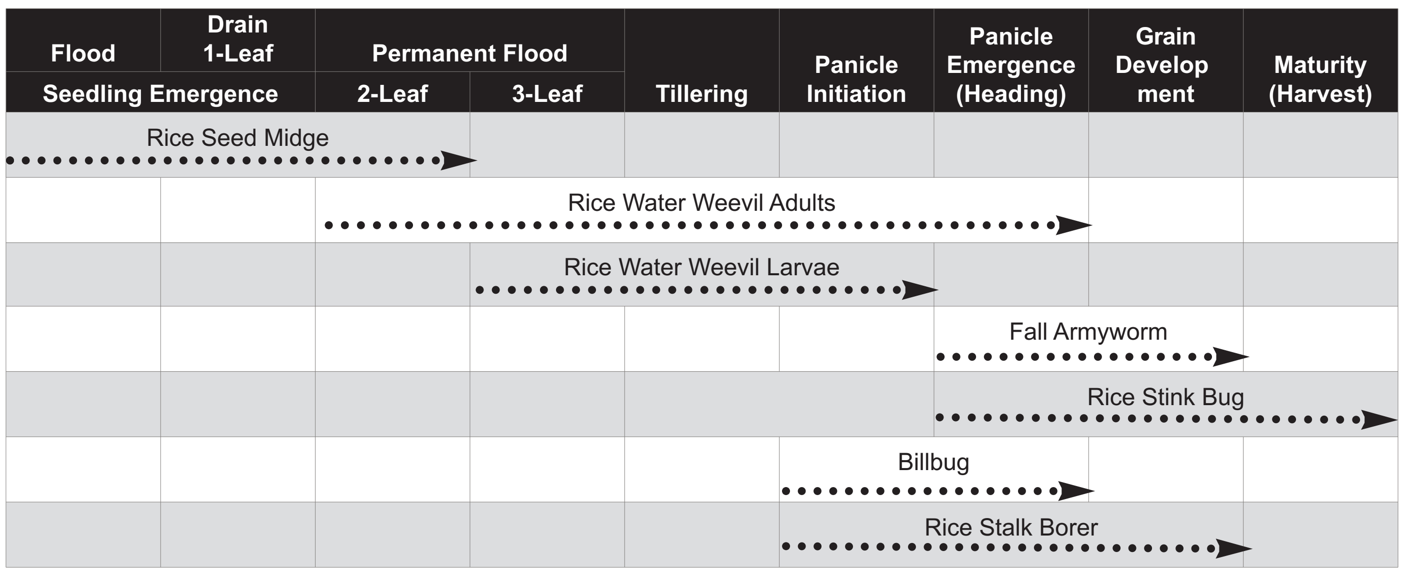


Figure 12-2. **Insects impacting water-seeded rice and growth stages affected.**

of the ventral fleshy projections on the abdominal segments. Pupae construct earthen cells in the soil.

Photo 12-1. Adult grape colaspis beetle.

Photo 12-2. Grape colaspis larvae (lespedeza worm).

Life Cycle as Related to Rice and Soybean

Legumes such as soybeans are the primary host for grape colaspis. They are often found in corn and other weedy legume species. Adults lay eggs in legumes and corn. The larvae (third through eighth stage) overwinter deep in the soil. In the spring, larvae move upwards in the soil profile seeking roots and underground stems on which to feed. Because legumes and corn are often rotated with rice in the Mid-South, grape colaspis larvae often have only rice on which to feed. Larvae usually complete development on rice. However, rice is not a primary host that adult grape colaspis uses for egg laying.

Damage and Symptoms

Larvae and adults are commonly found in legumes such as soybean, with multiple generations per year common. The last generation of larvae descends deep into the soil to overwinter. In the spring, grape colaspis larvae move up toward the soil surface and resume feeding. Because leguminous crops are rotated with rice, larvae often only have rice on which to feed.

When overwintered larvae reach the root zone, feeding occurs on the seedling rice roots and the portion of the plant stem (mesocotyl) between the germinated seed and the soil surface. Larvae girdle the below-ground stem until only an unsevered threadlike portion remains (Photo 12-3). Girdled seedlings become yellowed, stunted and wilted. Under stress, many damaged plants will die. These symptoms resemble and, therefore, are easily confused with seedling disease and salinity injury.

Photo 12-3. Damage by grape colaspis larvae on stem between seed and base of plant (right) compared to normal (left).

Plants with less than two leaves are very susceptible to damage by grape colaspis. Older plants may also be injured, but more damage is necessary for these plants to show above-ground symptoms. Some larvae complete development on rice, pupate and adults emerge later in the spring. In general, grasses, including rice, are not host plants for adults and are not used for egg laying. Grape colaspis injury occurs only to dry-seeded rice.

When rice follows soybean, low to moderate densities of grape colaspis are often found. Areas of damage are randomly distributed and characterized by 6- to 10-inch row sections with plants showing damage symptoms. Silt and sandy loam soils will have more problems with grape colaspis than heavy clay soils. Increased use of reduced tillage rice production systems on silt and sandy loams has shown a higher frequency of problems with grape colaspis.

Scouting and Management. No formal sampling plan is available to scout for grape colaspis. Often, below-ground damage is completed before above-ground symptoms are noticed. If grape colaspis damage is suspected, examine the seedlings, roots and soil from a 2- to 4-inch-deep soil sample. Carefully inspect plants for evidence of grape colaspis damage. Grape colaspis injury has historically been a problem in rice on silt loam soils. However, clay soils are rarely affected. Confirmation of grape colaspis presence or underground injury symptoms is needed because above-ground symptoms may resemble seedling diseases or soil problems (high salt or pH).

Insecticides. Insecticide seed treatments including Cruiser® 5FS (Syngenta Crop Protection) and NipsIt INSIDE (Valent Corporation) have been tested extensively in Arkansas for control of grape colaspis. Based on these studies, we have concluded that Cruiser and NipsIt INSIDE are recommended for grape colaspis.

Foliar applications of pyrethroids such as Mustang Max and Karate followed by a rain or flushed in may aid in suppressing grape colaspis. The application should be made with preemergence herbicide up to 1- to 2-leaf rice. Fields should be flushed within 2 to 3 days after application to incorporate the insecticide in the rice root zone for maximum activity. Recent studies have shown this approach to be largely ineffective.

Cultural Control. Methods to reduce grape colaspis damage in dry-seeded rice are (1) deep spring tillage and (2) flush fields and hold water for at least 48 hours. Deep tillage (disking) in early fall and late spring tends to disrupt larval cells and kill some larvae. Recent trends towards conservation tillage in rice and soybeans are coincident with a higher frequency of problems with grape colaspis.

Fields that are actively encountering a grape colaspis problem can be "temporarily flooded" (flushed). Flushing may kill some small larvae and dislodge others. The primary purpose of flushing is to keep the soil moist so that some moderately and slightly damaged plants can replace roots and avoid water stress. It is recommended that water be held for a minimum of 48 hours. An application of fertilizer, such as urea, ammonium sulfate or DAP, is often applied to fields ahead of the flush to aid in recovery. While the plants are stressed, the fertilizer may not be of much assistance. However, as the plants begin to recover, uptake of the fertilizer will enhance seedling growth so that the plant will increase tolerance to feeding from grape colaspis.

Management Key

In areas with a history of grape colaspis, we strongly recommend the use of an insecticide seed treatment.

Rice Water Weevil
[*Lissorhoptrus oryzophilus* (Kushel)]

Description

Adult rice water weevils are snout beetles about ⅛ inch long. When dry, the adults are grayish-brown with black markings on the back but are uniformly dark brown when wet (Photos 12-4 and 12-5). Eggs are placed in the leaf sheath and are fragile, pearly-white, cylindrical with rounded ends and about 1⁄32 inch in length.

The larvae, sometimes called "root maggots," are white, legless, range in size from 1⁄32 to 3⁄16 inch in length and have a brown head (Photo 12-6). Abdominal segments two through seven have a pair of hooks or bumps on the dorsal surface of the body. The hooks are primarily used to obtain oxygen from plant roots and may also be used to aid in movement. The larva has respiratory tubes that distribute oxygen throughout the body of the insect. Pupation occurs in an oval, watertight silken cocoon covered with a thin layer of soil which is attached to the roots.

Life Cycle

Adults enter diapause and overwinter in accumulated leaf litter around trees, in the base of bunch grasses and in other sheltered places. The indirect flight muscles degenerate while adults overwinter. In the spring, flight muscle regeneration is regulated by temperature. Following flight muscle regeneration, adults leave overwintering sites, usually in late April through late May, and fly during early-morning and evening hours. Adult rice water weevils are attracted to open water. Adults feed on host plants, including rice, leaving white, linear feeding scars parallel to the leaf veins and midrib (Photos 12-5 and 12-7).

Photo 12-4. Rice water weevil adult.

Photo 12-5. Leaf scars from adult rice water weevil feeding.

Photo 12-6. Rice water weevil larva.

Adults move under debris or into cracks in the soil during the day and emerge in the evening to feed. If the soil becomes too dry, adults will leave a dry area and search for more moisture. Leaf scarring can be heavy, but even the heaviest scarring will not result in yield loss. Heavy scarring is usually seen in field areas with deep water and/or thin stands, such as near the levees.

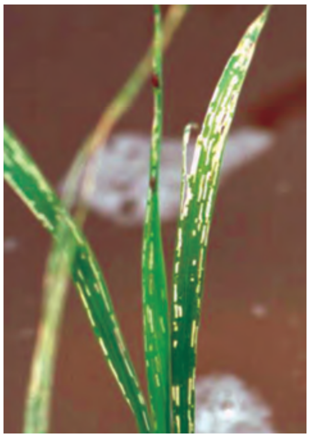


Photo 12-7. **Leaf scars from adult rice water weevil feeding.**

Feeding by adults on rice leaves will begin soon after rice emergence and continue until after internode elongation. Once the fields are flooded, rice water weevils already in the soil and others that fly into the field begin feeding and searching for mates. In flooded rice fields, the indirect flight muscles of 80 to 90 percent of adults begin to degenerate and render adults flightless in about 5 to 7 days.

Females begin to lay eggs about 1 to 2 weeks after emergence from overwintering but only when part of the host plant is submerged in water. The majority of eggs are deposited within 2 weeks. Eggs hatch in 4 to 9 days (depending on temperature). The larvae may feed in the leaf sheath for a short time before chewing a hole in the leaf, sinking to the soil surface and burrowing into the soil to feed on roots. Larvae are the damaging stage of the life cycle. Small larvae often enter the larger roots to feed and cause the death of the whole root. Larger larvae damage roots through external feeding. Larvae complete development in about 4 weeks.

Pupation occurs in an oval, watertight cocoon covered with a thin layer of soil which is attached to the roots. The pupal stage typically lasts 7 to 10 days. The time from egg to adult takes from 35 to 40 days in the southern U.S. but may take up to 75 days in California.

In Arkansas, first-generation adults (from hatched eggs) feed on rice leaves from June to early September before finding a site to overwinter. Overwintered adult rice water weevils begin to die in July. A small percentage of first-generation adults will deposit eggs in rice, giving a partial second generation. Adult weevils are commonly found on rice panicles. Adults will feed on the rice flowers when the hulls are open and the floral parts are exposed. However, the rice hull is an effective barrier and keeps adults from feeding on the kernel. Economic damage is not expected from rice water weevil adults found on rice panicles. In Louisiana, two complete generations and a partial third generation are present each year. Rice water weevils in the other rice-producing states have generations similar to those in Arkansas.

Damage and Symptoms

Adults feed on rice leaves and cause white, linear feeding scars parallel to the leaf veins (Photo 12-4). While the feeding scars may be heavy, yield loss does not occur. The rice water weevil causes yield loss when the larvae feed on the rice root system and can cause severe injury (Photo 12-8). When the rice root system is damaged by larval feeding, plant uptake of nutrients is reduced and plants may exhibit nutrient deficiency symptoms (usually N). Plants will not usually show deficiency symptoms unless root damage is severe or availability of nutrients is low. Severe root pruning may cause rice to turn yellow, reduce growth (stunting), delay maturity and, when severe, reduce yields. Plants with a severely pruned root system may lean in the water or float when physically disturbed.

Photo 12-8. **Roots injured by rice water weevil larvae feeding.**

The severity of rice water weevil infestation in any rice field is related to several factors:

1. The weevil population in the area during previous years.
2. Availability and proximity of “good” overwintering sites.
3. Overwintering survival.
4. The sequence of flooding of rice fields in the area.
5. Rice cultural seeding method (drill-seeded or water-seeded).
6. Stand density, water depth and rice cultivar.

Yield loss attributed to rice water weevil damage is usually greater in water-seeded than in drill-seeded fields. Water-seeded rice will begin to attract adults when seedlings (one to two leaves with a small root system) emerge from the water and will continue to attract adults for several weeks. In comparison, drill-seeded rice will begin to attract adults when rice has four to five leaves, developed tillers and has a more developed root system when flooded. Thus, drill-seeded rice is attractive to colonizing adult rice water weevils for only 1 or 2 weeks after flood establishment. Larval densities peak 21 to 35 days after flooding in drill-seeded rice and 28 to 42 days after permanent flooding in water-seeded rice. Adults and larvae are usually present in higher densities for a longer time in water-seeded rice.

Scouting and Management

Sampling for Rice Water Weevil Larvae. The oldest scouting method in rice, larval counts, is not often used today because insecticides that were used in the past are no longer available and foliar-applied insecticides currently used are targeting the adult stage, not the larval stage. However, this method may be used to decide on nonchemical management decisions, such as pulling the flood and draining the field, which may reduce larval injury or aid in plant recovery. Other scouting methods have become more useful in scouting for adults, which are the target for current foliar insecticides. Scouting for larvae is the same in drill-seeded and water-seeded rice and should be conducted 2 to 3 weeks after permanent flooding.

Rice plants and soil that surrounds the root system can be used to determine the larval infestation. The size of the soil/plant sample should be 4 inches in diameter and 3 to 4 inches deep in a silt loam soil and 2 to 3 inches deep in a heavy clay soil. Place the soil/plant sample in a bucket that has a 40-mesh screen bottom. Wash the soil from the plants by vigorously swirling the plants in the water to dislodge larvae from the roots. Move the sample vigorously up and down in the water several times to help wash away the soil. Most larvae will float to the water surface and can be removed from the bucket and counted. Continue to repeat the soil removal motions and larval counts until no additional larvae float to the surface or are visible in debris inside the bucket. Additional samples may be needed in large fields. The number and size of larvae can be used to predict how much damage has and/or will occur in dry-seeded rice, **if the samples are taken during peak densities**. Recent studies in Texas indicate a yield loss of 1 percent for every larva per core.

Leaf Scar Counts. In drill-seeded rice, begin scouting and using leaf scar counts 2 to 7 days after the field is flooded. Examine only the youngest mature leaf for adult feeding scars on plants at least 6 feet from levee furrows (barrow or bar ditch). Do not count scars on older leaves. Scouting procedures should ensure that representative field areas are scouted. Counts will generally be higher along tree lines and levees than in any other part of the field. At each stop, inspect 40 plants and record the number of plants with at least one scar on the youngest mature leaf. If a treatment decision cannot be made after a reasonable number of stops, scout the field again in 4 to 5 days. When the percentage of the youngest mature leaves with feeding scars equals or exceeds 60 percent in drill-seeded rice, control measures are justified.

For water-seeded rice, begin scouting and using leaf scar counts when seedlings emerge from the flood. Follow the same procedures as described for drill-seeded rice. When the percentage of plants with at least one adult feeding scar on the youngest mature leaf equals or exceeds 50 percent, an insecticide application is recommended. The treatment threshold is lower for water-seeded rice because rice plants are smaller and more susceptible to damage. Leaf scar thresholds for water-seeded rice are preliminary and subject to change with additional research, so check with your county Extension agent for the latest recommendations.

For control of rice water weevil adults, the leaf scar method should be used for only the first 2 weeks after the permanent flood is established, regardless of the cultural seeding method. In rice fields where an insecticide seed treatment is used, leaf scar counts may not be effective as a treatment threshold. Insecticide seed treatments can provide control of larvae feeding on roots but do not necessarily prevent leaf feeding by adults. However, under intense pressure, extremely high leaf scar counts can be evidence that insecticide seed treatments may be overwhelmed and a supplemental foliar insecticide application may be justified. In these situations, leaf scar counts may need to be supplemented with larval counts.

Counting Rice Water Weevil Adults. Scouting of rice water weevil adults can be an effective way to determine the need for control measures. Fields should be scouted during the first 4 to 7 days after flooding. If fields take more than 10 days to flood, growers should check the first levees that have been flooded for 4 to 7 days for weevils. All fields should be inspected for the abundance of adult water weevils. The key to observing adults is to scout fields in the morning hours between 8 and 10 a.m. when adults move out of the water onto plants for feeding. If the average field-wide density of rice water weevil adults exceeds one adult per row foot, the chemical treatment for rice water weevils is justified. If less than the whole field is infested at a rate less than one adult per row foot, then treating only the heavily infested areas could be sufficient. An application of an insecticide to control rice water weevil adults can be made using observations on weevil density.

Days After Flooding. For fields that have a history of heavy rice water weevil infestations, treatment decisions can be made solely on the number of days after flooding. In general, a single application of an insecticide timed between 5 and 9 days after permanent flood will control rice water weevil adults. In all previous research studies, insecticides applied 10 or more days after permanent flood did not effectively control rice water weevils.

Management Key

An insecticide application to control adults can be timed using observations on weevil density, counting leaf scars or on the days after the field has been flooded.

Insecticides. The only foliar insecticides currently labeled for control of rice water weevils need to be applied to kill adults or newly-layed eggs. Thus, the timing of application should be when adults are abundant but before the peak egg-laying period. An application after the majority of eggs have been laid will be ineffective. In drill-seeded rice, peak egg laying could occur at any time between 5 and 14 days after the permanent flood.

Four insecticides are currently available for rice water weevil control. The relative efficacy rating is presented in Table 12-1 and the recommended rates and timings are shown in Table 12-2. Three of the products are synthetic pyrethroid insecticides applied only for the control of rice water weevil adult. These products are Declare, Karate Z, Mustang Max, Proaxis and Prolex and have provided similar results. Application(s) should be timed when adults are abundant but before peak egg laying occurs. For drill-seeded rice, peak egg laying could occur between 5 and 14 days after

Table 12-1. Rice insecticide performance ratings.

	Restricted Use	Chinch Bug	Fall Armyworm	True Armyworm	Short Horned Grasshopper	Rice Stink Bug		Rice Water Weevil			Rice Stalk Borer	Aphids (Greenbug, Oat Bird, Cherry Aphid)	Grape Colaspis
						Adults	Eggs and Immatures	Adults	Larvae	Eggs			
Seed Treatments													
Dermacor X-100	X	1	8	8					8.5		8		2
Cruiser	X	6		2				6	7				8
Nipsit Inside	X	6		2				6	7				8
Foliar Insecticides													
Declare/Prolex	X	7	8	8	7	8	8	9				8	
Dimilin 2 L	X							0	8	7			5
Lambda-cyhalothrin†	X	7	8	8	7	8	8	9				8	
Malathion		1	2	5	6	6	5	0				4	
Mustang Max	X	7	8	8	7	8	8	9				8	
Sevin		6	6	5	6	8	5					1	
Tenchu	X					8	8						

†Includes other products containing lambda-cyhalothrin.

Table 12-2. **Insecticides labeled for rice water weevil control†.**

Insect	Type of Damage	Timing of Treatment	Treatment	Active Ingredient /Acre	Product Rate/Acre	Preharvest Interval
Rice Water Weevil adults	Prevent adults from laying eggs	**Drill-Seeded:** Apply Karate Z, Prolex, Proaxis, Declare and Mustang Maxx within 10 days after permanent flood when adults are present. **Water-Seeded:** Apply Karate Z, Prolex, Proaxis, Declare, and Mustang Maxx within 7 days after permanent flood when adults are present; a second application may be necessary 5 to 7 days later. DO NOT apply Belay after 3rd tiller initiation. DO NOT apply to rice that has clothianidin seed treatment. Hold water for 14 days after treatment.	**chlothianidin** Belay 2.13	0.075 lb	4.5 fl oz	
			gamma-cyhalothrin Prolex/Declare 1.25 CS Proaxis 0.5 CS	0.0125 – 0.02 lb	1.28 – 2.05 fl oz	21 days
			lambda-cyhalothrin	0.025 – 0.04 lb	3.2 – 5.12 fl oz	21 days
			zeta-cypermethrin Mustang Max 0.8 EC	0.02 – 0.025 lb	3.2 – 4.0 fl oz	14 days
larvae	Prevent larvae from damaging roots	See insecticide seed treatments in Table 4-6.				
eggs	Prevent eggs from hatching	**Drill-Seeded:** Within 10 days after permanent flood when adults are present. **Water-Seeded:** Within 7 days after permanent flood when adults are present;	**diflubenzuron** Dimilin 2L	0.125-0.25 lb	12 to 16 fl oz	

† Labels are frequently changed, so always check the most recent label of any insecticide for directions and restrictions prior to application. Insecticides applied to heading rice have a pre-harvest interval. Be sure to know the pre-harvest interval before application

‡There are many formulations of lambda-cyhalothrin; make sure to read the label for appropriate rates.

permanent flooding. An application of a pyrethroid can be timed with leaf-feeding scars or on days after flooding if a field has a history of rice water weevil damage. A single application timed between 5 to 10 days after permanent flooding may give adequate control in most rice fields, when needed. Application 10 days after flooding will not likely give adequate control since peak egg laying may have occurred. **The floodwater cannot be released within 7 days after application of a synthetic pyrethroid.**

In water-seeded rice, pyrethroids should be applied when adults are present and leaf scars are found on 50 percent of the youngest leaves. Carefully scout water-seeded rice after the first application for the presence of adult weevils since a second application may be necessary 5 to 7 days after the first application. Pyrethroid applications, whatever the seeding method, should be made during the morning hours (approximately 9 to 11 a.m.). Application during this time will be most effective due to the behavior of adult weevils. The synthetic pyrethroid insecticides may have a short residual time, depending on application rate and environmental conditions. The synthetic pyrethroid insecticides do not interact with herbicides. Always check and follow the most recent label of any insecticide for use directions and restrictions.

Dimilin 2L is an insect growth regulator that has activity against rice water weevil eggs. Dimilin needs to be in the water when adults are present and actively laying eggs. Timing of Dimilin application(s) is the key to controlling rice water weevil with this product.

The recommended Dimilin 2L rates that have been tested are 0.187 and 0.25 pound ai per acre (12 or 16 ounces of product per acre). In water-seeded rice, Dimilin should be applied when adults are present and leaf scars are found on 50 percent of the youngest leaves. A split application of 0.095 or 0.125 pound ai per acre (6 or 8 ounces per acre) after the leaf scar threshold is reached followed by another 0.095 or 0.125 pound ai per acre (6 or 8 ounces per acre) in 5 to 7 days will improve control of rice water weevil. The split application is recommended for water-seeded rice since egg laying is extended and the peak may not occur until 7 to 28 days after permanent flooding. A split application in dry-seeded rice may improve control of rice water weevil if infestation is continuous (extended). Dimilin does not interact with herbicides.

Cultural Methods. Control of rice water weevils can be accomplished by cultural or chemical means. One alternative to insecticide control is water management. Often called "drain and dry," this cultural practice involves the removal of water from the field 10 to 14 days after permanent flooding. The DD50 period for drying soil for straighthead prevention can also be used for rice water weevil control. Drying the soil is effective if the soil is allowed to dry thoroughly. Incomplete drying may not sufficiently reduce the number of larvae. Draining and drying the soil needs to be accomplished in 10 days or, preferably, less. Rain or slow drying conditions may reduce its effectiveness. If more than 10 days is required to drain and dry, then weeds can reinfest and become a problem.

"Drain and dry" is a remedial cultural practice that should be considered if currently registered insecticides were not used and scouting has shown a density of larvae that may cause enough damage to reduce the yield. Other factors such as water availability, weed control, straighthead history or cultivar susceptibility, fertilizer management and growth stage must be considered before drying a field for rice water weevil control. This practice can be cost prohibitive due to fuel prices. Also, drying the field at this stage in the season can increase weed problems, delay maturity, impact fertilization, and may enhance blast problems.

Planting date can have an influence on rice water weevil infestation. When flooded, fields planted during the usual early dates will attract overwintered adults and can have low to high infestations. Fields that are planted after the majority of rice is planted will generally have fewer weevils available and infestations will be low to moderate. Late-season planted rice will attract the first generation adults and will tend to have high infestations.

A cultural practice that influences rice water weevils but is normally not done specifically for this reason is delaying the permanent flood. The normal delay of flood until the 4- to 5-leaf growth stage (21 to 35 days after emergence) allows plants to develop a sizeable root system and conveys tolerance to root feeding from rice water weevil larvae. Another benefit of delayed flooding is the preferences of adult weevils for suitable plants. Previous research has shown that adults lay eggs in plants of all ages. However, when given an array of plants at different ages, the highest larval densities were found in plants 20 to 30 days of age (Table 12-3).

This may imply that rice water weevils infest a field shortly after permanent flood, but all may not remain if plants are not of suitable age. Other research by agronomists showed that yield was not reduced if permanent flood was delayed for an additional 7, 14 or 21 days. The use of an extended delayed flood as a cultural practice to lower the number of rice water weevil larvae can be successfully used by rice growers. When the flood is delayed an additional 10 days longer than normal, yields are not reduced, heading is not delayed and weevils are reduced. Neonicotinoid seed treatment efficacy against rice water weevil begins approximately 35 days after planting. Dermacor X-100 provides better control of rice water weevil after this window, but provides little to no control of grape colaspis.

Table 12-3. Effect of extended delayed permanent flood on densities of rice water weevils in plots of rice of different ages and grain yields.

Year	Plant Age at Flood	Rice Water Weevils Larval Density† 3 WAF	4 WAF	5 WAF	Grain Yield
	days	larvae/core			bu/A
2001	20	43.3	32.3	16.8	199
	30	22.6	22.5	8.7	219
	40	14.2	8.8	6.0	218
2002	20	36.4	32.1	26.2	178
	30	18.3	19.8	13.6	184
	40	15.8	11.3	9.8	188

† WAF = weeks after flood.

Drill-seeded rice followed by delay of the permanent flood allows plants to grow to the 4- to 5-leaf growth stage and develop a sizable root system. Water-seeded rice with continuous flood has water on small plants with a small root system. Rice water weevils are attracted to flooded rice where females lay eggs in the leaf sheath. Therefore, water-seeded rice plants are susceptible to water weevils for a longer time than drill-seeded rice. More weevils over a longer period of time results in too much damage (root pruning) for unprotected plants to overcome for normal grain yield in this system (Figure 12-3). Growers who utilize water seeding should be aware of the increased risk and the seriousness of problems that can occur as the result of rice water weevils. Chemical control of rice water weevils in water-seeded rice is needed in almost every situation. In furrow-irrigated rice systems, rice water weevil is less of a threat due to the lack of flooded conditions; however damage may still occur in locations where water pools for an extended period of time.

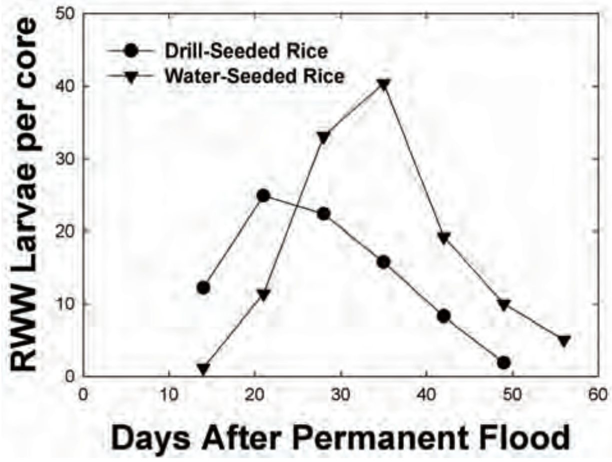


Figure 12-3. Number of rice water weevil larvae in untreated drill-seeded and water-seeded rice.

Another alternative to insecticides is supplemental nitrogen application. Growers commonly apply extra N fertilizer to treat the N deficiency symptoms that result from damage to the rice root system. Research data is presently unavailable to confirm the benefit of supplemental N application. The efficiency of fertilizer N uptake by plants with damaged root systems is reduced. However, application of low N rates (30 to 45 pounds N per acre) near, but before, mid-season may help damaged plants recover. Mid-season N application rates may also need to be increased to compensate for larval damage. Be aware that application of extra N fertilizer is treatment of a symptom caused by the larval feeding. Extra N may help if the larval population has peaked and is declining.

Management Key

Nitrogen deficiency induced by rice water weevil feeding may be corrected by an application of urea near, but before, midseason. Slow uptake may result if roots are damaged to the point of restricting the amount of nitrogen that is taken up by the plant.

The severity of a rice water weevil infestation in any particular field is related to several factors which include:

- The weevil population in the area during the previous year(s).
- Availability and proximity of suitable overwintering sites.
- Overwintering survival.
- The sequence of flooding of rice fields in the area (planting date).
- Other factors such as cultivar, production systems, stand density, and flood depth.

Biological Control. Rice water weevils have several natural enemies that provide some degree of biological control. A mermithid nematode was discovered in a small percentage of adults. The extent and control provided by this nematode remains unknown. Several aquatic predators found in rice fields may also attack adult weevils. Long-horned grasshoppers and small green katydids, common in and near all rice fields, readily feed on adult weevils when adults become numerous shortly after permanent flooding. The impact of all general aquatic predators remains unquantified.

Rice Stink Bug [*Oebalus pugnax* (F.)]

Description

The adult rice stink bug has reddish antennae and a body similar to the color of mature rice grains (Photos 12-9 and 12-10). The rice stink bug's body is about ⅜ to ½ inch in length. The rice stink bug can be distinguished from other stink bugs by the pointed spines, with points directed forward and slightly outward, that are located on the shoulders. Adult stink bugs overwinter in accumulated leaf litter around trees, in the base of bunch grasses, and in other sheltered places. Emergence from overwintering sites generally begins in April and continues to the end of May, depending on the temperature and location in Arkansas.

Photo 12-9. Adult rice stink bugs mating.

Photo 12-10. Rice stink bug adult.

The rice stink bug has several cultivated and wild plant hosts. Cultivated hosts include grain sorghum, oats, rice, rye, and wheat. There are about 40 wild host plants, but the availability of barnyardgrass, bearded sprangletop, dallisgrass, lovegrass (*Eragrostis* sp.), ryegrass (*Lolium* sp.), crabgrass, broadleaf signal-grass and several species of *Panicum* are very critical to seasonal stink bug populations. Weedy grasses (wild host plants) are essential to rice stink bug survival, but eggs are not placed in all host plants upon which adults feed. Stink bug longevity (life span) and fecundity (number of eggs) are influenced by which host plants rice stink bug nymphs and adults feed on.

Stink bug eggs are always placed in two parallel lines on leaves, stems or panicles of host plants (Photo 12-11). Each egg mass contains 20 to 40 eggs but have been reported to range from 10 to 70. Individual eggs are barrel-shaped and about 1/25 inch long and 1/50 inch in diameter. When first layed, stink bug eggs are green but eventually turn red before hatching. Eggs hatch in 4 to 7 days, depending on temperature, and first instars remain clustered around the egg shells.

Photo 12-11. Just-hatched rice stink bug nymphs clustered near egg shells.

Nymphs pass through five distinct instars and do not have wings or shoulder spines. The first instar is about 1/25 inch long with all black body parts except the abdomen which is red with two or three black spots (Photo 12-11). The second through fifth instars gradually increase in size and are light brown with red and black spots on the abdomen (Photo 12-12). First instars do not feed on rice. Older nymphs (second through fifth instar) primarily feed on seeds. Total time spent as a nymph is between 15 and 28 days.

Photo 12-12. Rice stink bug nymph.

Female stink bugs start egg laying 3 or 4 days after becoming an adult. Egg laying gradually decreases and eventually stops in old adults. Adult stink bugs that overwintered begin to die in mid-July. Adults, like nymphs, feed primarily on seeds and remain active in host plants until the host plant becomes senescent or cool weather arrives. At least four generations of rice stink bug occur each year in Arkansas.

Life Cycle

Adults overwinter in leaf litter, clumps of grass or in other sheltered places. In Arkansas, emergence from overwintering sites occurs in late April and early to mid May. A series of cultivated and wild hosts are used during the season and are critical to population survival and increase. Cultivated hosts include heading wheat and oats (rye and barley also) early in the season and then grain sorghum later in the season. Grasses (weeds/wild hosts) are essential to rice stink bug survival before rice, the favored host, is available. The list of host plants is extensive and includes barnyardgrass, bearded sprangletop, dallisgrass (*Paspalum* sp.), vaseygrass (*Paspalum* sp.), lovegrass (*Eragrostis* sp.), ryegrass (*Lolium* sp.), crabgrass (*Digitaria* sp.), broadleaf signalgrass (*Panicum* sp.), johnsongrass and many others. Rice stink bugs do not place eggs in all cultivated and wild hosts upon which the adults feed. The life span and the number of eggs that females produce are influenced by the host plants. Rice stink bugs are estimated to produce four generations each year.

Eggs hatch in 4 to 7 days and the nymphs remain clustered around the egg shells. The first instar does not feed on plants but may ingest water. The second through the fifth instar feeds primarily on seeds. Total time spent as a nymph is between 15 and 28 days. After becoming an adult, females start depositing eggs in about 3 to 4 days. Egg laying gradually decreases and eventually stops in old adults. Adult longevity has been observed to average about 50 days. Overwintered adults begin to die in mid July. Adults are active in plant hosts until a host becomes senescent and/or cool weather arrives.

Table 12-4. Insecticides labeled for rice stink bug control†.

Insect	Type of Damage	Timing of Treatment	Treatment	Active Ingredient /Acre	Product Rate/Acre	Preharvest Interval
Rice Stink Bug (nymphs and adults)	Both stages suck juices from kernel, causing blanks and/or discolored rice kernels	5 bugs per 10 sweeps at heading; 10 bugs per 10 sweeps 2 weeks after heading; scout in morning for best results. Terminate application at an average of 60% hard dough down the panicle.	**carbaryl** Sevin 80S, 80WSP Sevin 4L, 4F, XLR	1.0 – 1.5 lb	 1.25 – 1.87 lb 2 – 3 pt	14 days
			dinotefuran Tenchu	0.094 – 0.13 lb	 7.5 – 10.5 fl oz	7 days
			malathion Malathion 57% EC	0.625 – 0.94 lb	 1 – 1.5 pt	7 days
			gamma-cyhalothrin Prolex / Declare 1.25 CS Proaxis 0.5 CS	0.0125 – 0.2 lb	 1.28 – 2.05 fl oz 3.2 – 5.12 fl oz	21 days
			lambda-cyhalothrin‡	0.025 – 0.04 lb		21 days
			zeta-cypermethrin Mustang Max 0.8 EC	0.0165 – 0.025 lb	2.64 – 4.0 fl oz	14 days

† Labels are frequently changed, so always check the most recent label of any insecticide for directions and restrictions prior to application. Insecticides applied to heading rice have a pre-harvest interval. Be sure to know the pre-harvest interval before application.

‡There are many formulations of lambda-cyhalothrin; make sure to read the label for appropriate rates.

Damage and Symptoms

Adults and nymphs have piercing-sucking mouthparts. Entry of the stylets (mouthparts used for feeding) is facilitated by a salivary secretion that hardens on contact with air and remains attached to the rice grain. The secretion is called a feeding sheath (Photo 12-13). The feeding sheath is the only external evidence that feeding by rice stink bugs has occurred on grain. No hull discoloration is associated with feeding by rice stink bugs. The stylet penetrates the hull allowing the stink bug to feed on the developing rice kernel.

Photo 12-13. Rice stink bug feeding scars on a rice kernel.

The amount and type of rice stink bug damage depends upon the stage of rice kernel development. Feeding at any time before the milk stage stops any further development of the kernel, resulting in yield loss (Photo 12-14). Feeding during the milk (Photo 12-15) and soft dough stages (Photo 12-16) may result in the removal of all or part of the contents (also a yield loss). Pathogens are introduced into the kernel by rice stink bug feeding. Infection of the kernel by pathogens (fungi and bacteria) and enzymes produced by the rice stink bug can cause discoloration and weakening of the kernel (quality loss). Discolored kernels often break during milling procedures, resulting in reduced quality (Photo 12-17). During the first 2 weeks of heading, damage from each adult rice stink bug will total two to six lightweight kernels and two to six discolored kernels per day. During the third and fourth weeks after heading, adult feeding activities will cause one to five discolored kernels and one to two light weight kernels per day. Grains discolored by rice stink bug feeding activity remain attached to the panicle. Lightweight, damaged kernels are often lost with straw and chaff at harvest. Partially filled and discolored kernels are mixed with undamaged grain.

Management Key

Rice stink bug typically causes yield and quality losses during the first 2 weeks after heading and primarily quality losses (pecky rice) during the third and fourth weeks after heading. Add Terminate insecticide applications at 60% hard dough.

An excessive amount (1 percent or higher) of discolored kernels in grain can result in lower grade and price when the grain is sold. All discolored kernels, whatever the cause, are called “pecky rice.” Rice stink bugs are not the sole cause of pecky rice but contribute to the total. Control of potentially damaging populations of rice stink bugs can reduce the amount of discolored kernels and improve rice grade, quality and selling price. Stink bug infestations and resulting injury tend to be cyclical from year to year. The highest infestations were observed in 2001 and 2011.

Photo 12-14. Rice stink bug feeding during early development of rice kernels (normal kernel at left).

Photo 12-15. Rice stink bug feeding during milk stage of rice kernels.

Photo 12-16. Rice stink bug feeding during the soft dough stage of rice kernels.

Photo 12-17. Broken kernels during milling resulting from rice stink bug feeding.

Scouting and Management

Stink bug populations in rice fields should be scouted weekly or preferably twice weekly beginning at 75 percent panicle emergence and continuing until grain maturity (30 to 35 days after 50 percent heading). Scouting during the morning hours of 8 to 11 a.m. or evening hours of 7 to 9 p.m. will provide better estimates of rice stink bug densities. Rice stink bug adults are alert to disturbances and movement and are quick to fly.

Scouting is done using a 15-inch diameter insect sweep net to sample rice stink bugs. At each sample site, make 10 consecutive 6-foot wide sweeps to determine rice stink bug densities. Sweeps should be taken at a quick pace to provide distance between each sweep to assure the same area is not swept twice. Sweeps should be done from side-to-side in front of the sweeper's body. The top rim of the sweep net should pass 2 to 3 inches above the rice heads, with the majority of the rim encompassing rice panicles. After each 10-sweep sample, grasp the net under the ring to keep the insects from escaping. Slowly open the net and count adults and nymphs of the rice stink bug. Repeat the sampling procedure at several random sites (ten or more). Calculate the average number of rice stink bugs per 10 sweeps. Usually, weedy host plants are more abundant along field margins and will attract more rice stink bugs.

Management Key

For best results, scout for rice stink bugs early in the morning (before 9 a.m.) or late in the evening (after 7 p.m.).

Insecticide application is recommended if stink bug densities average five or more per 10 sweeps during the first 2 weeks of heading. During the third and fourth week of heading, applications are recommended when rice stink bug densities exceed 10 individuals per 10 sweeps. If the sample density is slightly above or below the threshold or if the field is very large, additional samples will improve confidence in population estimates. Insecticide applications are warranted through hard dough until 60 percent hard dough is observed across 50 percent of the field. In this case, hard dough is defined as a turn from green kernels to straw-colored kernels (Photo 12-18). Similar to recommended scouting times, insecticides should be applied in the morning (8 to 11 a.m.) or late evening (7 to 9 p.m.) for best control. Insecticides available for control of rice stink bugs are listed in Table 12-4. Always consult the label prior to use.

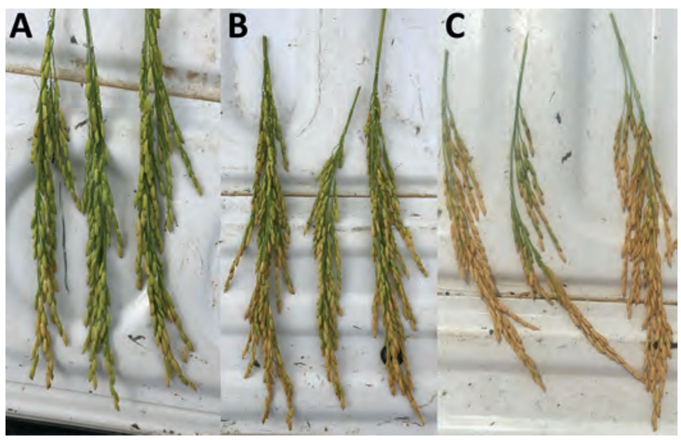


Photo 12-18. Rice panicles below 60% hard dough (A), at 60% hard dough (B), and above 60% hard dough (C).

Management Key

Apply insecticides for control of rice stink bugs when more than 5 bugs per 10 sweeps are present during the first 2 weeks after heading or 10 bugs per 10 sweeps during the third or fourth weeks after heading. Terminate insecticide applications at 60 percent hard dough.

When sampling near weedy areas and field borders, note the stink bug counts in these areas. Treatment of field borders or isolated field areas where stink bugs are concentrated, rather than the entire field, may be feasible.

Photo 12-19. Proper sweepnet method for sampling rice stink bug.

Insecticides. Insecticides available for control of rice stink bugs are carbaryl (Sevin XLR), lambda-cyhalothrin, zeta-cypermethrin (Mustang Max) and gamma-cyhalothrin (Prolex, Proaxis). Applications should be made in the morning (8 to 11 a.m.) or late evening (7 to 9 p.m.) in 5 to 10 gallons of water to get the best results. Sevin will have some initial kill with 3 to 5 days of residual activity. The synthetic pyrethroid insecticides (lambda-cyhalothrin, Mustang Max, Prolex, Proaxis) have good initial kill and 1 to 2 days of residual activity. When high stink bug densities are observed along field margins and low densities are within the field, treatment of field borders using a quick-kill insecticide should be considered. The floodwater cannot be released within 7 days after application of a synthetic pyrethroid.

Management Key

Insecticides are most effective if applied prior to 9 a.m. or after 7 p.m.

Biological Control. Several predators and parasites have been reported to attack rice stink bugs and are important biological control agents. Among them are two species of parasitic flies (*Tachinidae*) that attack nymphs and adults but at low levels of parasitism (1 to 15 percent parasitism). Tiny wasps may also parasitize and kill eggs. The wasp parasite (*Telenomus podisi*) is very active throughout the year in all host plants of the rice stink bug (Photo 12-20). High levels of control (greater than 90 percent) have been documented in wild host plants when rice stink bugs are concentrated (>20 bugs per 10 sweeps). Even at lower densities of adults, parasitism usually averages slightly above 70 percent in some weed hosts. Rates of parasitism in rice fields is usually low (2 to 20 percent). Egg masses that are black, not the usual red or green, show parasitism by the wasps. Blackbirds and green tree frogs feed on rice stink bug adults, and long-horned grasshoppers will feed on eggs and nymphs (refer to grasshopper section for more information on grasshoppers).

Photo 12-20. Egg parasite feeding on rice stink bug eggs.

Cultural Controls. Rice cultivars differ in susceptibility to the rice stink bug, as evidenced by the amount of discolored grains in cultivars. Susceptibility to damage tends to be greatest in short grains, somewhat less in medium grains and usually the lowest in long grains. However, within a grain type, the susceptibility also varies. Some rice cultivars appear to be more susceptible due to differences in rates of panicle maturity or other factors.

Wild host plants are important to the survival and abundance of rice stink bugs. Reduction of weed hosts in and around rice fields will aid in the reduction of rice stink bugs. Rice cultivar and grain type (long, medium or short) are also important factors that influence the amount of rice stink bug damage. Usually, stink bug damage is greatest in short-grain cultivars and least in long-grain cultivars. Seeding date may also influence the amount of stink bug damage. Rice stink bugs may concentrate in the earliest maturing fields as well as the latest maturing fields.

Minor Rice Insects

Rice is sometimes damaged by insects that originate in and prefer crops other than rice. Examples of these crossover pests include armyworms and aphids. Occasionally rice stalk borers, billbugs, rice seed midges, short-horned grasshoppers, fall armyworms, chinch bugs or rice root aphids will become numerous and may cause noticeable damage to rice. A brief description of these pests and possible cultural and chemical control measures are provided in the following section.

Armyworms: True Armyworm [*Pseudaletia unipuncta* (Haworth)] and Fall Armyworm [*Spodoptera frugiperda* (J.E. Smith)]

Description

True armyworms and fall armyworms both fall into the armyworm complex but have distinguishing characteristics between one another. The adult moth for true armyworm have a wingspan of about 1½ to 1¾ inches. The color of the forewings is tan with a single, small, white spot midway across the width and length of the wing. Hind wings are gray or gray-brown. Fall armyworm moths have a similar wingspan as true armyworms, spanning from 1½ to 1¾ inches. The forewings on fall armyworm adults is are mottled dark gray with a prominent white spot at the extreme tip of the wing. The hindwings are a white color with a purple sheen.

Moths are active at night and lay eggs in large masses behind the leaf sheath of host plants. Armyworm adults are often transported with weather fronts moving from the west and south into Arkansas. Adults are not known to lay eggs directly into rice.

True armyworm larvae (caterpillars) can be either green or brown but have a distinctive pattern of longitudinal stripes – a dark stripe along each side and broad stripe along the back (dorsal stripe) (Photo 12-21a). The dorsal stripe has a lighter colored broken line down the center. The head is pale brown with green and brown mottling. Fall armyworm larvae (caterpillars) vary in color from light tan or green to nearly black. Larvae have three yellow-white thin lines running down the back of the caterpillar (Photo 12-21b). On both sides of the body next to the yellow thin lines is a wider dark stripe. Fall armyworm larvae also have a distinct inverted y on their head capsule (Photo 12-21c).

Life Cycle

Some armyworm larvae or pupae may survive Arkansas winters to emerge in the spring. Larvae often become numerous in wheat or oat fields before or shortly after heading. Large larvae sometimes leave the wheat fields and move into adjacent areas as the wheat heads mature and the foliage begins to desiccate. If a rice field is adjacent, damage usually occurs near the border of the two crops and seldom is found over the entire field. Pupation can occur in rice fields, but adults are not known to deposit eggs directly onto rice.

Armyworms can also be found in fields that have a growth of winter/spring weeds. Growers must be aware of this situation and not plant rice too early after application of a burndown herbicide. Allow the foliage on weeds to die to prevent the armyworms from moving from the weeds to seedling rice.

Damage and Symptoms

Armyworms feed on leaves and stems and may consume the entire above-ground rice seedling. The growing point is usually not damaged and seedlings normally recover; however, crop maturity can be

Photo 12-21. True armyworm larva (A), fall armyworm larva (B) and inverted "Y" of fall armyworm (C).

delayed (Table 12-5). Older plants that are defoliated will be delayed more than younger plants.

Table 12-5. **Comparison of undamaged plants with simulated armyworm damage.**

Growth Stage When Damaged†	Heading Delay	Grain Yield Loss‡
	days	bu/A
2-leaf	2	5.2
3-leaf	4	9.3

† Plants were cut to ¼ inch above the soil surface at the 2- or 3-leaf growth stage.
‡ Francis rice seeded at 100 lb/acre.

Scouting and Management

No formal scouting plan or treatment threshold is used for armyworms in rice. Growers should observe rice fields next to wheat or oat fields that contain armyworms and watch for movement between the crops. Treatment should be applied before severe damage occurs to prevent stand reduction. If plants become water stressed as the result of feeding, yield losses can be observed.

Insecticides available for control of armyworms are listed in Table 12-6. The timing between applications of herbicides containing propanil and carbamate insecticides is critical. Certain insecticides inhibit the action of an enzyme present in rice that prevents rice from being killed by grass herbicides. Thus, rice sprayed with propanil can be killed or severely injured if a carbamate insecticide follows or precedes propanil. The severity of damage depends on the time between the applications and the class of insecticide. If a carbamate insecticide (i.e., Sevin) is used, a waiting period

Table 12-6. **Insecticides labeled for control of other rice insects†.**

Insect	Type of Damage	Timing of Treatment	Treatment‡	Product/Acre
Short-Horned Grasshoppers (nymphs and adults)	Leaf feeding and head damage	Treat where damage is evident; border treatment may be beneficial	Lambda-cyhalothrin Mustang Max 0.8 EC Proaxis 0.5 CS Prolex/Declare 1.25 CS	0.025-0.04 0.0165-0.025 0.0125-0.20 0.0125-0.20
Chinch Bug (nymphs and adults)	Reduce plant stand by sucking sap	When insects are causing stand reduction	Belay 2.13 Lambda-cyhalothrin Mustang Max 0.8 EC Proaxis 0.5 CS Prolex/Declare 1.25 CS Sevin 4L,F, XLR Sevin 80S, 80WSP	0.075 0.025-0.04 0.0165-0.025 0.0125-0.20 0.0125-0.20 1.0-1.5 1.0-1.5
Fall Armyworm (larvae) True Armyworm (larvae)	Flag leaf and panicle feeding reduces yield Plant feeding may reduce stand or delay growth	Treat when six or more armyworms per square foot. Later in the season, treat when fall armyworms are present and damaging the flag leaf.	Dermacor X-100 Lambda-cyhalothrin Mustang Max 0.8 EC Proaxis 0.5 CS Prolex/Declare 1.25 CS	0.06-0.08 0.025-0.04 0.0165-0.025 0.125-0.20 0.125-0.20
Rice Stalk Borer Sugarcane Borer (larvae)	Cause deadhearts before heading and white heads at heading	Apply at boot stage and/or panicle emergence for suppression of white heads	Lambda-cyhalothrin Proaxis 0.5 CS Prolex/Declare 1.25 CS	0.025-0.04 0.125-0.20 0.125-0.20
Aphids, Greenbug, Birdcherry-Oat Aphid (nymphs and adults)	Reduces stand and causes stunting	Treat when 2-3 greenbugs per 1-2 leaf rice or when plants become yelllowed and stunted	Belay 2.13 Lambda-cyhalothrin Mustang Max 0.8 EC Proaxis 0.5 CS Prolex/Declare 1.25 CS	0.075 0.025-0.04 0.0165-0.025 0.0125-0.20 0.0125-0.20

† Labels are frequently changed, so always check the most recent label of any insecticide for directions and restrictions before application. Insecticides applied to heading rice have a pre-harvest interval. Be sure to know the pre-harvest interval before application.
‡ **CAUTION:** Insecticides listed for rice insect control may interact with propanil causing severe injury to rice unless timed properly. Do not apply malathion or Sevin within 14 days before or after propanil applications. If insecticides are necessary and the time frame suggested cannot be followed, consider herbicide options other than propanil. Many generic lambda-cyhalothrin materials are available, be sure to read the label for appropriate rates.

of 14 days before or after propanil is recommended. Moderate injury may be observed even when the waiting period is observed. However, rice can be killed if the waiting period is not followed. Problems with lethal interactions can be avoided by using one of the synthetic pyrethroid insecticides (i.e., Declare, lambda-cyhalothrin, Mustang Max, Prolex, Proaxis) since they do not interact with herbicides. However, the floodwater cannot be released within 7 days after application of a synthetic pyrethroid. Reduced damage and lower densities of armyworms have been observed when Dermacor X-100 was used as a seed treatment.

Recent observations indicate Dermacor X-100 seed treatment will control true armyworm larvae on seedling rice. However, the larvae must feed on the plant to die and some damage may occur on field edges where the larvae enter the field.

Management Key

Use caution if using propanil herbicide and applying malathion or a carbamate insecticide. Be sure to adhere to the recommended waiting period.

Aphids: Greenbug [*Schizaphis graninum* (Rondani)] and Bird Cherry-Oat Aphid [*Rhopalosiphum padi* (L.)]

Description

Adults are small, oval, soft-bodied insects with or without wings. Near the tip of the abdomen are two tubelike structures called cornicles. Two species, the greenbug (Photo 12-22) and the bird cherry-oat aphid, have been reported in rice. The greenbug has a pale green or yellowish-green body, pale green legs with dark tips, a dark green stripe down the center of the abdomen and pale green cornicles with black tips. The bird cherry-oat aphid has a purplish-green to dark purple body, legs with black tips, cornicles with black tips, and at the base of the cornicles is a reddish-orange spot across the bottom half of the abdomen.

Photo 12-22. Adult and nymph greenbugs.

Life Cycle (as Related to Wheat, Weeds and Rice)

The greenbug and bird cherry-oat aphids are common pests of wheat. Aphid infestations are rare in rice fields and normally do not begin in rice. Aphids that have infested wheat or adjacent weedy areas move into rice. Before 1996, greenbugs were an uncommon pest in rice fields. That year, greenbugs were often found feeding on rice and reduced stands in many fields. The bird cherry-oat aphid was first reported in rice in 1997. Each year since, fewer fields have been reported to be infested with these pests. However, severe infestations do still occur.

Damage and Symptoms

Aphids have piercing-sucking mouthparts and feed on plant sap. The greenbug also injects a toxin into the plant while feeding. The symptoms of aphid feeding include stunted plants, curled leaves or leaves that fail to unroll or light green, yellow, red or brown discolorations on the leaves. The toxin causes yellowing of leaves, and small plants may die with heavy feeding. Seedling rice plants with one to two leaves have been killed with only two to three greenbugs per plant or four to five bird cherry-oat aphids per plant. Larger plants with two or three greenbugs per plant may be stunted and turn yellow but have not been reported to die. However, other unknown consequences of aphid infestation on larger plants may result but are not obvious.

Scouting and Management

Thresholds are not available for treatment of aphids in rice. However, should greenbugs become numerous (two to three greenbugs per 2-leaf or smaller rice; four to five bird cherry-oat aphids per plant), insecticide application may be beneficial. Synthetic pyrethroid insecticides are mostly effective against aphids and do not interact with commonly used rice herbicides (Table 12-6).

Conservation tillage practices where herbicides are used to kill weeds prior to planting often encourage infestation of aphids in rice. It is recommended to

Table 12-7. Quick threshold guide for rice insect pests.

Insect	Threshold	Scouting Procedure
Chinch bug	Treat when bugs are causing stand reduction.	Check seedling rice, particularly fields bordering wheat.
Fall armyworm, true armyworm	Treat when 6 or more armyworms per square foot early season. Late season treat when fall army-worms are damaging flag leaf.	Early season watch rice bordering wheat for migration of true armyworms into field (damage can occur quickly when armyworms move in).
Grasshopper	Treat when damage is evident.	Watch field borders, particularly near grassy areas.
Greenbug	2 to 3 greenbugs per plant on 1- to 2-leaf stage rice.	General visual observation.
Stink bug	5 stink bugs per 10 sweeps during first 2 weeks of panicle emergence. 10 stink bugs per 10 sweeps after first 2 weeks of panicle emergence.	Sample for stink bugs during the morning hours or late evening. Stink bug levels are difficult to estimate during high daytime temperatures.
Rice water weevil		Inspect the youngest leaf on 40 rice plants at each stop for adult feeding scars. Avoid areas with thin stand. DO NOT count older leaves with scars.

wait until the treated plants show definite signs of leaf death before planting rice. If rice is planted too early following the burndown herbicide, aphids present in the weeds can damage and destroy rice seedlings.

Rice Stalk Borer [*Chilo plejadellus* Zincken]

Description

The adult rice stalk borer is a moth with a wingspan of about 1 to 1½ inches (Photo 12-23). The forewings are white or light brown with randomly placed very small black scales or spots. Edges of each forewing have a row of very small metallic gold and black spots. Hind wings are white or light brown. Eggs are pearly white, flattened and laid in masses with eggs overlapping and resembling a pattern similar to fish scales. Larvae are light brown with one longitudinal dark brown stripe on the center of the back and one light brown stripe along each side of the body (Photo 12-24). Mature larvae have a length of 1 to 1½ inches. Pupae are dark brown. The first confirmed infestation in Arkansas was found in Chicot County in 1981. Since then, the rice stalk borer has been found in all counties with rice in Arkansas, including southwest Arkansas, the Arkansas River Valley and all of eastern Arkansas.

Photo 12-23. Adult rice stalk borer.

Photo 12-24. Rice stalk borer larva.

Life Cycle

Larvae overwinter in rice stubble and pupation occurs in the stem during the spring. Moths emerge in May (based on ultraviolet light traps) and lay eggs only in flooded rice. Eggs are placed in masses of 10 to 30 eggs on the top or bottom side of the leaf and sometimes behind the leaf sheath. Eggs hatch in 5 to 6 days. Eggs can be placed on plants to which permanent flood has just been applied or later in the season when the panicle is just about to emerge. The small larvae from a single egg mass enter one or more rice plants by chewing a hole either behind the leaf sheath or near the base of the panicle (Photo 12-25). More than one larva may enter the stem through a single hole. The larvae eat the inner stem tissue beginning at the entry point and move downward (Photo 12-26). Mature larvae chew

Photo 12-25. Entry hole into stem made by a borer larva.

through the tissues until only a single thin layer covers a circular hole in the stem wall above the water line. Very seldom does more than one larva reach maturity in a single stem. When several small larvae enter the same plant, most exit the plant when half grown and infest nearby rice plants. The adult escapes through the hole.

Photo 12-26. Nearly fully grown rice stalk borer larva near the bottom of the stem.

Damage and Symptoms

Larvae feed on the vascular stem tissue from the inside, effectively halting translocation of nutrients and water. If the plant is infested any time after permanent flooding but before heading, the main stem may die but not the tillers (called a deadheart). Likewise, if the larvae enter behind the leaf sheath of a tiller, the tiller may die but not the main stem. If the plant is infested just before emergence of the panicle, the green panicle emerges, but soon all the florets turn white (whitehead; See Photo 12-27). Larvae that enter a plant after panicle emergence may cause panicles to be partially filled. Whiteheads are more numerous on edges of fields, paddy edges beside levees and on plants in the bar ditches. Fields bordered by weedy ditches or wooded areas often have higher infestations.

Photo 12-27. Whitehead (blank panicle) due to rice stalk borer in flooded rice or billbug on levee.

Scouting and Management

No formal scouting plan has been devised for sampling rice stalk borer and, therefore, no thresholds have been established for chemical treatment.

Insecticides. Insecticide application for the rice stalk borer is usually not recommended. Infestation and losses are usually not enough for economic return. Recently, stem borers were added to the label of synthetic pyrethroid insecticides registered in rice (Table 12-6). This recommendation was in response to problems with stem borers in Texas. Recent studies also show Dermacor X-100 seed treatment can give control or suppression of stalk borers. For fields that have a history of severe rice stalk borer infestations, an application is recommended at panicle initiation to reduce deadhearts and again at boot stage rice to reduce whiteheads. However, treatment for rice stalk borer is seldom warranted in Arkansas.

Cultural Control. Because larvae overwinter in rice stubble, any method of stubble destruction, such as plowing, rolling, burning or flooding, should reduce the number of larvae that survive overwintering in the field. Fields that will be flooded for waterfowl habitat should have the rice stubble rolled, including stubble near and on the levees, to reduce overwinter sites. Any stubble left standing beyond the end of March will positively influence the survival of overwintering larvae. Seeding date also impacts infestation by rice stalk borer. As planting becomes later, rice stalk borer infestations increase exponentially (Figure 12-4).

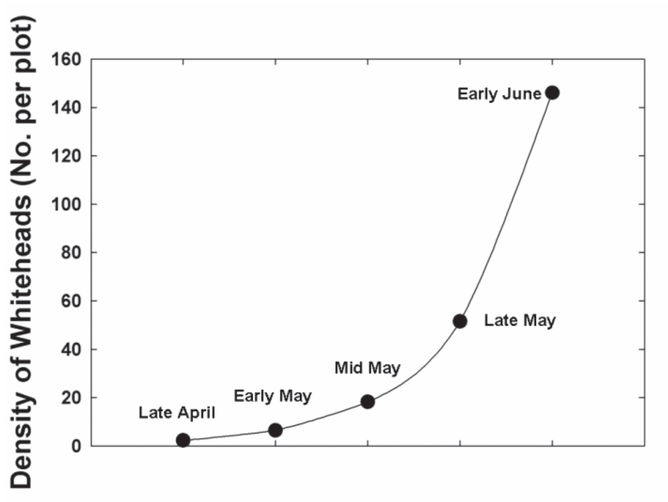


Figure 12-4. Influence of planting date on infestation by rice stalk borer.

Biological Control. Some degree of biological control is provided by an egg parasite (*Trichogramma minutum*) that has been recovered from rice stalk borer eggs. The amount of parasitism by these egg parasites is unknown but is certainly important. High rates of parasitism have been observed late in the season.

Sugarcane Borer
[*Diatrea saccharalis* (E.)]

Description

Adult moths have a 1 to 1½ inch wingspan with straw-colored forewings and darker markings (Photo 12-28). Hindwings are a straw color. The size of the moth varies with the amount of food (host plant) taken by the larvae. The eggs are oval and flattened, laid in clusters with the individual eggs overlapping so that a pattern like fish scales is formed. Egg masses usually consist of 50 eggs or less. Larvae are yellowish white with brown spots (Photo 12-29). Overwintered larvae are more deeply yellow with the color of the spots very light or absent. Mature larvae have a length of about 1 to 1½ inches. The first confirmed infestation in Arkansas was found in Desha and Chicot counties in 2003.

Photo 12-28. Adult sugarcane borer.

Photo 12-29. Sugarcane borer larva.

Life Cycle

Larvae overwinter in rice, corn and grass stubble. Pupation occurs in the spring, and adults emerge in May. The number of generations each year in Arkansas is unknown. Egg masses are placed on the leaf and sometimes behind the leaf sheath. Eggs hatch in about 5 days. The small larvae can enter the plant by chewing a single hole near the base of the panicle or, more commonly, the larvae can mine the leaf sheath for a short time, then enter the plant stem (Photo 12-25). The larvae eat the inner tissues of the stem, grow larger and push excrement (frass) through a hole and out of the stem (Photo 12-30). Mature larvae chew through the stem until only a very thin layer of tissue remains. The circular hole in the stem is above the water line and allows the adult to escape. Pupation occurs in the rice stem. Very seldom does more than one larva mature in a single stem. When several small larvae enter the same plant, most exit the plant when half grown and infest nearby rice plants.

Photo 12-30. Frass from sugarcane borer larva.

The following list of host plants has been recorded for the sugarcane borer: the cultivated crops of sugarcane, corn, sorghum and rice; the wild hosts johnsongrass (*Sorghum halepense*), Sudangrass (*S. bicolor* ssp. *drummondii*), giant broomsedge (*Andropogon* sp.), vaseygrass (*Paspalum urvillei*), fall panicum (*Panicum dichotomiflorum*), Amazon sprangletop (*Leptochloa panicoides*), and broadleaf signalgrass (*Urochloa platyphylla*). Stages of sugarcane borer are found only in Amazon sprangletop, johnsongrass and vaseygrass in Louisiana.

Damage and Symptoms

Larvae eat inner tissues of the rice plant stem and effectively stop any translocation of nutrients and water. If the rice growth stage is just after permanent flood when the larvae enter the plant, the main culm or tillers may die (deadheart). If the growth stage is just prior to emergence of the panicle when the larvae enter the plant, the green panicle emerges but soon turns white (whitehead). What is different from the rice stalk borer is that sugarcane borers enter more plants lower on the stem and later in panicle development. This causes more partial whiteheads.

Scouting and Management

No formal scouting plan has been devised for sampling for sugarcane borer and no thresholds have been formed.

Insecticides. Insecticide application for the sugarcane borer is usually not recommended. Infestation and losses are usually not enough for economic return. Recently, stem borers were added to the label of synthetic pyrethroid insecticides registered in rice. This recommendation was in response to the problems with three species of stem borers in Texas. In Texas, an application is recommended at panicle initiation to reduce deadhearts and again at boot stage rice to reduce whiteheads. Again, treatment(s) for stem borers is usually not recommended in Arkansas.

Cultural Control. Larvae overwinter in rice stubble. Any method of stubble destruction such as plowing, rolling, burning, or flooding should certainly lower the number that survives overwintering. Leaving stubble standing beyond the end of March would positively influence the survival of overwintering larvae. If fields are to be flooded for ducks, then rolling of stubble including that near the levees is highly recommended. Sugarcane borer infestations are generally concentrated on field edges and edges of paddies near levees.

Data obtained indicate that heavy pasturing of stubble reduces the number of overwintering larvae by 75 percent. Burning of stubble also decreases the number of larvae (note: burning must be complete to reduce larvae). Fields plowed in the fall had less than 1 percent of larvae surviving the winter. A high mortality of overwintering larvae was found if the field was flooded during the winter. A flood depth of 5 inches was required to get 40 percent mortality if stubble was left standing. However, if stubble were rolled and then flooded the mortality was increased to 85 percent.

Precaution: When rice and corn are grown in the same vicinity, the sugarcane borer infestation is usually heavier in both crops than where one is grown in the absence of the other. The increased infestations result from moths from rice stubble to give a heavy spring infestation to corn. Corn serves as a breeding place for borers which later infest rice.

Other Stem Borer Species

There are two other species of insects that cause similar damage to rice as the rice stalk borer and the sugarcane borer. Rice is a host for the European corn borer (Photo 12-31) and the Mexican rice borer (Photo 12-32). However, the Mexican rice borer has not yet been found in Arkansas. They have experienced problems with Mexican rice borer in Texas rice production and Louisiana has recently reported finding the pest in rice there.

Photo 12-31. Adult European corn borer.

Photo 12-32. Adult Mexican rice borer.

Billbug [*Spenophorus* sp.]

Description

The adult is a large black weevil ¾ to 1 inch in length with a prominent snout (Photo 12-33). The legless larvae (grubs) have a white body, a reddish-brown head and are ¾ inch long when fully grown (Photo 12-34).

Photo 12-33. Adult billbug.

Life Cycle

The billbug completes one generation per year. Adults overwinter in protected sites and along field margins. Emergence begins in mid April and lasts to mid May. Mating and egg laying occur in the spring. It is believed that the female chews a small cavity near the base of the rice plant and deposits a single egg, or the egg is laid in the soil. The grub begins to feed on inner tissues of the stem about 2 inches above and below the soil surface (into the root crown). Larvae pupate in the plant stem and adults emerge in late

Photo 12-34. Billbug larva in cavity at base of stem.

summer and early fall. Adults disperse by walking and only fly if harassed. Development is lengthy compared to many rice insects, taking 50 to 60 days.

Damage and Symptoms

Billbug-injured plants turn brown and die. Adults are known to feed on the rice plant stem and the leaf whorl. Rows of oblong holes in expanded leaves are evidence that feeding has occurred. Larval feeding inside the root crown and lower stem generally causes the plant to die. The main symptom that a stem is infested with a billbug larva is a whitehead (totally blank panicle) similar to the whiteheads caused by stem borers. Billbug larvae cannot survive flooded conditions, even when inside the plant stem. Therefore, the whiteheads caused by billbug larvae will be found mostly on levees. In contrast, rice stem borers cause whiteheads in the flooded parts of the field. It is not known how many generations occur each season, nor if rice is the only host plant.

Scouting and Management

No formal scouting system or thresholds have been developed and no insecticides are currently registered for billbug control. Billbugs have never been reported to be a major problem in conventionally-flooded rice fields. However, some reports of difficulty maintaining a stand of rice on levees has been reported.

Recently growers have increased interest in furrow-irrigated rice production. Experience derived through the Rice Research Verification Program (RRVP) has demonstrated that this production system results in billbug infestations much higher than normal. In two furrow-irrigated rice fields in the RRVP program, estimates of 10 percent yield loss were observed due to billbug injury. Current research is underway to develop a better understanding of the life cycle, insecticides for control and treatment thresholds for furrow-irrigated rice.

Rice Seed Midges
[Family *Chironomidae*]

Description

Adult midges resemble small mosquitoes and range in size from ⅜ to ⅝ inch. The mouthparts of midges are underdeveloped and adults are nonbiting. Larvae are light brown or red (bloodworms), very slender, legless, distinctly segmented and have a nonretractable head with opposable jaws. Mature larvae range from ⅛ to ⅞ inch in length, depending on the midge species. Several species have been found to damage rice.

Life Cycle

Adult midges prefer to lay eggs on open water. Masses of eggs are laid in strings held together by a sticky mucus-like material that forms a protective envelope around the eggs. Eggs hatch in 1 to 2 days. The larvae use silk, bits of mud and debris to build tubes on the soil surface. Larval development is completed in 7 to 10 days. Pupation occurs underwater in the tubes. Adults emerge in 2 to 3 days.

Damage and Symptoms

Severe damage to rice is limited to germinating seeds, germinated seeds and very young seedlings in water-seeded rice with continuous or pinpoint flooding. Larvae feed by chewing on the developing seed embryo, root shoots and young seedlings. Larvae are often found inside the seed hulls and in tubes built on the seed. Injury to seed embryos from feeding causes plant development to cease.

Scouting and Management

Water-seeded fields with continuous or pinpoint flooding should be checked for midge infestation and damage 2 to 5 days after seeding. Examine fields for midge larvae, tubes, injured seed and injured plants. Scouting should continue until plants are about 1 to 1½ inches tall. All midge larvae that will damage rice seed will be found on the soil surface or in tubes on the soil surface. The criteria used to determine if a field needs to be reseeded include:

- the number of viable seed per square foot
- whether larvae are present
- the number of plants per square foot

Depending on the number of larvae present, the field may need to be drained and dried before reseeding. If larvae are abundant, drain the field and dry the soil to at least ½ inch deep prior to reseeding the field.

Some midge larvae are red and called bloodworms. These larvae are relatively large (¾ to 1 inch long) and can be commonly found in the soil of rice fields before and after flooding. The abundance is related to the amount of decaying organic matter present in the soil. It is not known if bloodworms damage rice seedlings or injure rice seed as much as non-red midge larvae. However, no evidence has been collected to demonstrate significant injury from bloodworms.

Since fipronil (Icon) is no longer available, no insecticides are registered for control of rice midge. However, other steps can be taken to minimize the injury from rice midges.

- Fields should be seeded as quickly as possible after establishment of the flood.
- Use pregerminated seed to hasten stand establishment.
- Avoid seeding during periods of cool weather because cool temperatures will delay rice growth but will not delay midge infestations.

Fields should be flooded and seeded as quickly as possible. Delaying seeding after the flood is established allows midge densities to increase before the rice is seeded. Using pregerminated seed is critical for no-till water-seeded fields that have been flooded during the winter. Water-seeding during periods of cool weather delays seedling development and enhances the opportunity for feeding by rice midges.

Management Key

Use pregerminated seed and water seed during warm weather to minimize damage from rice seed midge.

Grasshoppers

Description

Two general types of grasshoppers are commonly found in rice. The two types are short-horned and long-horned grasshoppers. The short-horned grasshoppers have antennae that are shorter than the body, a robust body, a large rounded head and powerful jaws (Photo 12-35). The short-horned grasshoppers can be green, brown, yellow or a mix of the three colors. Long-horned grasshoppers have a slender body with antennae that are as long as or longer than the body (Photo 12-36). They are typically small (1 to 2 inches long) and nearly all green in color. The reference to "long-horned" or "short-horned" is in regards to the length of the antennae.

Short-Horned Grasshoppers [Family *Acrididae*] – Short-horned grasshoppers are usually not as abundant in or around rice fields. However, on occasion, these grasshoppers do become numerous and damage rice. Short-horned grasshoppers are generally found near field margins and on levees. The differential grasshopper [*Melanoplus differentialis* (Thomas)] is the most common short-horned grasshopper known to damage rice. The large hind legs have a row of black chevrons. Adults (1¼ to 1½ inches long) and nymphs have strong jaw muscles and are vegetation feeders. Rice leaves, stems and panicles are occasionally damaged, especially when alternate food sources becomes scarce.

Photo 12-35. Short-horned grasshopper (line = 1 inch).

Along the field or levee margins, short-horned grasshopper feeding may damage newly emerged panicles. The panicle stem may be damaged and result in a whitehead. Careful scouting of field borders can locate potentially damaging infestations. Treatment with an insecticide is at grower discretion and recommended whenever sufficient damage to panicles is evident. No formal scouting system is in place, and treatment is based on evidence of damage. Border treatments may be beneficial. Insecticides are available for control of short-horned grasshoppers (Table 12-5).

Long-Horned Grasshoppers [Family *Tettigonidae*] – The most common and abundant grasshoppers in rice are long-horned grasshoppers. Long-horned grasshoppers may outnumber short-horned grasshoppers by as many as 300 to 1. The adults and nymphs have weak jaw muscles and cause only minor damage to rice foliage. Before panicle emergence, long-horned grasshoppers primarily feed on other insects, including rice water weevils, midge adults, damselfly adults and leafhoppers. After heading, these grasshoppers feed exclusively on pollen while flower anthers

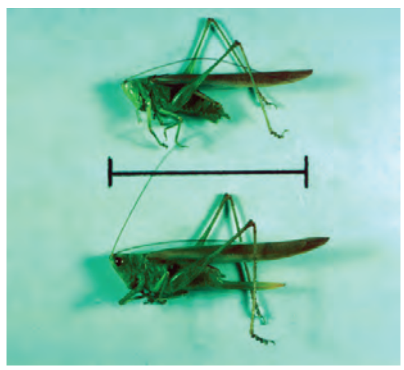


Photo 12-36. Long-horned grasshopper (line = 1 inch).

are available. A small amount of this feeding will damage flower parts and prevent pollination. However, the amount is small and not economically threatening. After flowering, long-horned grasshoppers scavenge anthers from florets at the bottom of the panicle, feed on whatever insects are available and may feed on kernels in the milk stage later in the season. Any kernels that these grasshoppers feed on are at the bottom of the panicle and are either immature or in the milk stage of development. This feeding does not result in an economically important loss. Insecticide application for long-horned grasshopper control is not recommended.

Chinch Bug [*Blissus leucopterus leucopterus* (Say)]

Description

Adults are about ⅕ to ⅙ inch long, black and have wings folded onto their backs that appear like a white "X." The first instar is orange and the other four instars have a black or dark gray head and thorax with a white or yellow band across the top of the abdomen. Both adults and nymphs have piercing-sucking mouthparts.


Photo 12-37. Adult chinch bugs on young rice.

Life Cycle

Adults overwinter in clump grasses. In late spring, adults leave overwintering sites and infest small grains such as wheat, corn, grain sorghum, oats and rice. Females lay eggs at the base of the host plant. By utilizing several hosts, chinch bugs may have as many as three generations per year, but overwintered adults do the most damage to seedling rice.

Damage and Symptoms

Damage is caused from chinch bugs by sucking sap from small plants. In rice, adults and nymphs can be found on nearly all plant parts, including the roots which can be accessed through cracks in the soil and around the plant base. Nymphs often cluster around the plant nodes. Symptoms of feeding injury include stunted plants, red or yellow areas on leaves and leaf sheaths and dead plants. Seedling rice plants are the most susceptible to damage. Severely damaged seedlings turn brown and die.

Scouting and Management

Very low densities of chinch bug adults can be found in almost any rice field. However, chinch bug numbers occasionally increase to damaging levels. Chinch bugs are relatively small, so examine inside whorled leaves, behind the leaf sheath, at the base of the stem and, if the soil is cracked, examine exposed roots. An average of two chinch bugs per 1- to 2-leaf seedling can cause significant seedling mortality, reduction in height and delay in maturity of surviving plants. Therefore, if chinch bug populations average two adults per plant, insecticide application is recommended. Observe fields for areas near the margins of the plants that have yellow or reddish spots and then check for the presence of adults and nymphs.

Should a field or area in a field become infested with chinch bugs, it is best if the field can be flushed prior to treatment. Flushing or flooding will move chinch bugs above the water line and onto the plants by closing the soil cracks. Any treatment will be more effective if the bugs are all on above-ground plant parts. Insecticides for chinch bug control include the synthetic pyrethroids (Declare, Mustang Max, Prolex, Proaxis) and carbaryl (Sevin) (Table 12-6). Remember to apply carbaryl 15 days before or after propanil. The synthetic pyrethroids can be applied safely before or after herbicide applications. However, floodwater cannot be released within 7 days after application of a synthetic pyrethroid. CruiserMaxx Rice and NipsIt INSIDE seed treatments provide suppression of chinch bugs.

The statements included in this chapter do not imply endorsement of any product and do not substitute for labeled insecticide restrictions. Insecticide use information on labels often changes, and labels should always be checked prior to use.

Chapter

13

Rice Grades

Jarrod Hardke and Terry Siebenmorgen

The United States Department of Agriculture (USDA) has established rice grades as U.S. No. 1 through 6, in which sample grade is based on quality discount factors. These factors include weed seed, red rice, seed mixture, damaged kernels, chalky kernels, etc. Grades and grade requirements for rough rice and milled rice and presented in Tables 13-1 and 13-2, respectively. Price discounts for milled rice in Table 13-3 are a general guide. These tables indicate the importance of producing clean, nondamaged rice.

Table 13-1. **Grades and grade requirements for the classes of rough rice, USDA, 2009.**

	Maximum limits of ----							
	Seeds and heat-damaged kernels				Chalky kernels			
	Total (singly or combined)	Heat-damaged kernels and objectionable seeds	Heat-damaged kernels	Red rice and damaged kernels (singly or combined	In long-grain rice	In medium- or short-grain rice	Other types†	
Grade	Number in 500 grams	Number in 500 grams	Number in 500 grams	Percent	Percent	Percent	Percent	Color requirements
U.S. No. 1	4	3	1	0.5	1.0	2.0	1.0	Shall be white or creamy.
U.S. No. 2	7	5	2	1.5	2.0	4.0	2.0	May be slightly gray.
U.S. No. 3	10	8	5	2.5	4.0	6.0	3.0	May be light gray.
U.S. No. 4	27	22	15	4.0	6.0	8.0	5.0	May be gray or slightly rosy.
U.S. No. 5	37	32	25	6.0	10.0	10.0	10.0	May be dark gray or rosy.
U.S. No. 6	75	75	75	15.0‡	15.0	15.0	10.0	May be dark gray or rosy.
U.S. Sample grade shall be rough rice which: a. does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 6 inclusive; b. contains more than 14.0 percent of moisture; c. is musty, or sour, or heating; d. has any commercially objectionable foreign odor; or e. is otherwise of distinctly low quality.								

† These limits do not apply to the class Mixed Rough Rice.
‡ Rice in grade U.S. No. 6 shall contain not more than 6.0 percent of damaged kernels.

Source: United States Department of Agriculture Federal Grain Inspection Service, *United States Standards for Rough Rice.*

Table 13-2. **Grades and grade requirements for the classes of long-grain milled rice, medium-grain milled rice, short-grain milled rice, and mixed milled rice, USDA, 2009.**

Grade	Maximum limits of ----											Color requirements	Minimum milling requirements
	Seeds and heat-damaged kernels (singly or combined)		Red rice and damaged kernels (singly or combined)	Chalky kernels		Broken kernels				Other types‡			
	Total	Heat-damaged kernels and objectionable seeds		In long-grain rice	In medium- or short-grain rice	Total	Removed by a 5 plate†	Removed by a 6 plate†	Through a 6 sieve†	Whole kernels	Whole and broken kernels		
	No. in 500 grams	No. in 500 grams	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent		
U.S. No. 1	2	1	0.5	1.0	2.0	4.0	0.04	0.1	0.1	--	1.0	Shall be white or creamy.	Well milled.
U.S. No. 2	4	2	1.5	2.0	4.0	7.0	0.06	0.2	0.2	--	2.0	May be slightly gray.	Well milled.
U.S. No. 3	7	5	2.5	4.0	6.0	15.0	0.1	0.8	0.5	--	3.0	May be light gray.	Reasonably well milled.
U.S. No. 4	20	15	4.0	6.0	8.0	25.0	0.4	1.0	0.7	--	5.0	May be gray or slightly rosy.	Reasonably well milled.
U.S. No. 5	30	25	6.0	10.0	10.0	35.0	0.7	3.0	1.0	10.0	--	May be dark gray or rosy.	Reasonably well milled.
U.S. No. 6	75	75	15.0††	15.0	15.0	50.0	1.0	4.0	2.0	10.0	--	May be dark gray or rosy.	Reasonably well milled.
U.S. Sample grade shall be milled rice of any of these classes which: a. does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 6, inclusive; b. contains more than 15.0 percent of moisture; c. is musty or sour, or heating; d. has any commercially objectionable foreign odor; e. contains more than 0.1 percent of foreign material; f. contains two or more live or dead weevils or other insects, insect webbing or insect refuse; or g. is otherwise of distinctly low quality.													

† Plates should be used for southern production rice; and sieves should be used for western production rice, but any device or method which gives equivalent results may be used.
‡ These limits do not apply to the class Mixed Milled Rice.
†† Grade U.S. No. 6 shall contain not more than 6.0 percent of damaged kernels.

Source: United States Department of Agriculture Federal Grain Inspection Service, *United States Standards for Milled Rice.*

Factors Affecting Rice Grade

Grain Moisture Content

Rice milling yield may be lower if rice is harvested either at very high or low moisture contents. At high moisture contents, many kernels can still be thin and immature and often break during the milling process. The ends of wet rice kernels grind off and become dust when they are processed. Rice may fissure if it dries to below 15 percent moisture content and is rapidly rewetted (e.g., rainfall, heavy dew). Rapid rewetting is a key cause for lowered head rice yields. Certain cultivars may be more susceptible to head rice yield reductions than others if rice drops below 15 moisture and is rewetted in the field.

Plant no more rice acreage of one maturity range than you have harvest capacity. The best way to extend combine capacity is by planting cultivars with different maturities. Planting over a longer period helps somewhat to spread rice maturity across more days in

Table 13-3. **Price discount estimates for USDA grades of milled rice.**

Grade	Discount ($/bushel)
1	--
2	0.05
3	0.15
4	0.30
5	0.45
6	0.80
Sample	1.25

the fall and provides a more flexible harvest window. Refer to Chapter 15, Production Factors Impacting Rice Milling Yield, for more information on the impact of harvest moisture content on milling yields.

Head Rice and Milling Yields

Head rice yield is the weight percentage of rough rice that remains as “whole rice” (three-fourths kernel or greater) after complete milling. Environmental conditions, such as drought, high nighttime temperatures, low sunlight intensity, disease, inadequate or excessive nitrogen and draining water early in hot weather, all intensify stress on rice kernels. The susceptibility of kernels to develop chalk or other kernel-weakening features in response to stress differs somewhat among cultivars.

Milled rice yield is the weight percentage of rough rice that remains as milled rice (i.e., the sum of head rice and “brokens” after milling). The value of broken fractions varies with market demand, but Table 13-4 illustrates that high milling yield and low foreign material content may provide considerably more income per acre. Refer to Chapter 15, Production Factors Impacting Rice Milling Yield, for more information on milling yields.

Foreign Matter

Foreign matter or trash (i.e., blank kernels, stems, weed seed) often contains more moisture than grain. Presence of this material can affect rice price and, ultimately, net profit (Table 13-4). Milling yield is lowered by the amount of foreign material in the rough rice sample. Foreign material contributes to heating on trucks, blocks air flow in grain storage bins and increases the time and energy required for drying. Consider cleaning rice that has high foreign matter content. Another alternative is marketing rice with high foreign material content separate from cleaner rice to maximize income.

Table 13-4. **Example of foreign material and low milling yield effects on rice price and net profit.**

Description	Sample 1	Sample 2	Sample 3
Sample weight, grams	162	162	162
Foreign material, grams	0	0	10
Head rice weight, grams	89	94	88
Brokens weight, grams	24	19	18
Milling yield percentage	55/70	58/70	54/65
Value per hundredweight†	$6.48	$6.60	$6.13
Difference in price/cwt	--	+$0.12	-$0.35
Value at 150 bu/A	$437.84	$445.95	$414.19
Value difference at 150 bu/A	--	+$8.11	-$23.65
Value at 200 bu/A	$583.78	$594.59	$552.25
Value difference at 200 bu/A	--	+$10.81	-$42.34

†Prices based on long-grain value of $10.13/cwt for head rice and $6.03/cwt for brokens.

Chapter

14

Laboratory Measurement of Rice Milling Yield

Terry Siebenmorgen

Laboratory milling systems are used throughout the rice industry to 1) estimate the milling yield that may be expected of rice lots when milled in large-scale milling systems and 2) produce milled rice samples from which visual, functional, sensory and nutritional assessments of the rice lot can be made. This chapter presents factors that can affect the laboratory measurement of rice milling yield, focusing on the use of the McGill #2 rice mill, a popular laboratory-scale mill used in the United States. Factors that affect the performance of this mill are detailed, as are properties of the rice that impact milling yield measurement. In particular, the degree of milling (DOM), the degree to which bran is removed from kernels during milling, is discussed in terms of its measurement and its effect on milling yield parameters.

Definitions

Definitions are provided to clarify terms commonly used in reference to milling yield measurement.

Rough rice is unprocessed rice with hulls intact; also often referred to as "paddy."

Brown rice is rice that remains once hulls have been removed from rough rice.

Milled rice is rice that remains once brown rice has been milled to remove the germ and a specified amount of the bran; this fraction includes both broken and intact kernels (head rice).

Milled rice yield (MRY) is the mass percentage of rough rice that remains as milled rice; often referred to as the "total" yield. Milled rice yield is calculated as:

$$MRY = \frac{\text{Milled rice mass}}{\text{Rough rice mass}} \times 100$$

Head rice comprises milled rice kernels that are at least three-fourths the original length of the kernel; often referred to as "whole" kernels or "fancy."

Head rice yield (HRY) is the mass percentage of rough rice that remains as head rice, calculated as:

$$HRY = \frac{\text{Head rice mass}}{\text{Rough rice mass}} \times 100$$

Milling yield is a term that is often referred to as "milling quality"; this term is often used in reference to HRY but also is routinely expressed as a ratio, with the numerator being the head rice yield and the denominator the milled rice yield. For example, a milling yield of 55/70 would indicate a HRY of 55 percent, a MRY of 70 percent and a brokens yield of 15 percent (the difference between MRY and HRY).

Degree of milling (DOM) is the extent of bran removal from brown rice.

Moisture content (MC[1]) is the mass percentage of a rice sample that is water (this is the definition of "wet basis" moisture content, which is predominantly used in the rice and grain industry), calculated as:

$$MC = \frac{\text{Mass of "wet" rice - Mass of completely dry rice (0\% MC)}}{\text{Mass of "wet" rice}} \times 100$$

[1] All moisture contents in this chapter are expressed on a wet basis.

Equilibrium moisture content (EMC) is the moisture content to which rice will equilibrate after an extended period of exposure to air at set temperature and relative humidity conditions; this is the state of the rice in which there is no moisture transfer between the rice and surrounding air.

Introduction

Laboratory-scale milling systems have long been used to estimate the milling performance that can be expected of a rice lot when milled in large, industrial-scale systems. Laboratory systems comprise equipment that first removes the hull from the rough rice kernel, producing brown rice. Brown rice is typically milled to remove the germ and bran layers, leaving milled rice. The predominant measurements of rice milling yield are made using the endosperm, or milled rice kernel. The degree to which the bran layers are removed from brown rice, the DOM, plays a significant role in determining overall milling yield and functional quality of milled rice.

Milling yield is quantified using two parameters, the milled rice yield (MRY) and head rice yield (HRY). Milled rice is the component of rough rice produced by removing the hulls, germ and desired amount of bran; milled rice includes intact and broken kernels. Milled rice yield is calculated as the mass fraction of rough rice remaining as milled rice. Broken kernels, defined by the USDA as kernels that are "less than three-fourths of whole kernels," are typically removed from milled rice. The remaining "whole" kernels are generally known in the milling industry as "head rice" and are those milled kernels at least three-fourths the original length of the kernel. Head rice yield is the mass fraction of rough rice that remains as head rice.

Both MRY and HRY are highly dependent upon the physical integrity of rough rice kernels, as well as the extent to which bran is removed during milling. In most markets, broken kernels are valued at only 50 to 60 percent that of head rice, thus underpinning the tremendous impact that HRY has on the economic value of a rice lot, and also justifying the need for laboratory milling systems to accurately determine this important parameter.

Laboratory Assessment of Milling Yield

The Federal Grain Inspection Service (FGIS) provides a methodology for conducting a milling yield analysis, which calls for using specified equipment/settings and a representative 1-kg sample of rough rice to be processed. It is common for practitioners to deviate from the FGIS procedure in terms of the equipment used and the amount of rough rice processed.

A typical laboratory huller is illustrated in Photo 14-1. The FGIS methodology specifies roller clearances for a McGill huller that prevent all rough rice kernels from being hulled in a single pass; setting the rollers to hull all kernels, particularly thin kernels, in a single pass will cause undue breakage. The *FGIS Rice Inspection Handbook* states that "after shelling, the sample contains 2 to 3 percent paddy kernels in long-grain rice or 3 to 4 percent paddy kernels in medium- or short-grain rice." Typically, roller clearances are set to allow at least 4 to 5 percent of long-grain rough rice kernels to be unhulled; this percentage varies slightly with the cultivar or cultivar mix being analyzed. In commercial mills, unhulled kernels from a huller are separated from brown rice and conveyed to another huller for a second hulling pass. In laboratory practices, the resulting brown rice kernels

Photo 14-1. A laboratory-scale rice huller (THU35B, Satake, Hiroshima, Japan).

and unhulled kernels from a huller are typically left mixed and subsequently milled together.

The resulting brown rice is milled, which for FGIS procedures constitutes using a McGill #3 mill (Rapsco, Brookshire, Texas, USA). The McGill #3 is designed to mill the brown rice produced by a 1-kg rough-rice sample. However, this amount of rice is often greater than is available, especially in research settings. Thus, smaller-scale mills are often substituted for laboratory use. Several companies have developed laboratory mills capable of milling lesser quantities of rice. Perhaps the most commonly used laboratory-scale mill in the U.S. rice industry is the McGill #2 mill (Rapsco, Brookshire, Texas, USA), illustrated in Photo 14-2. This batch-type mill has gained popularity over the McGill #3 because of its lower initial cost, as well as its lower electrical-power and sample-size requirements. Andrews et al. 1992 reported that the McGill #2 mill may be used with rough rice sample quantities as small as 125 g (yielding a resultant brown rice mass of approximately 100 g) and that settings could be adjusted to produce results equivalent to the McGill #3.

Photo 14-2. **A laboratory-scale rice mill (McGill #2, Rapsco, Brookshire, Texas, USA).**

After milling, broken kernels are then separated from head rice by some means. A common laboratory method for separating broken kernels from head rice employs a “sizing device,” often referred to as a “shaker table.” Such a device, illustrated in Photo 14-3, comprises two oscillating, inclined, indented plates with indentions sized according to the type of rice (short-, medium- or long-grain) to be sorted. The plate oscillation causes the greater-mass head rice to be conveyed ahead of the lesser-mass broken kernels. Head rice falls into a collection pan after passing over the second plate. The operator will terminate the sizing device operation when all head rice is collected and before brokens enter the collection pan.

Recent advances in imaging technology have allowed the introduction of laboratory instruments that estimate the percentage of head rice and broken kernels in a milled-rice sample based on kernel dimensional analysis rather than physical separation. While these imaging systems are effective in rapidly estimating HRY, separation of broken kernels is often necessary in laboratory settings in order to isolate head rice required for other quality and functionality assessments. Additionally, the cost of such imaging systems may necessitate the traditional sizing-device approach.

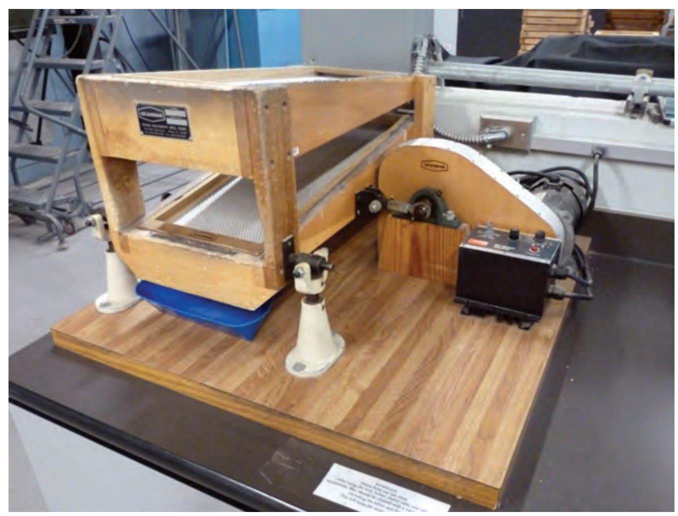


Photo 14-3. **A laboratory-scale rice sizing device (Model 61, Grain Machinery Manufacturing Corp., Miami, Florida, USA).**

It should be noted that milled rice is very susceptible to fissuring due to rapid moisture gain or loss, which is determined by the gradient in moisture content between that of the kernels and the rice EMC associated with the surrounding air temperature and relative humidity. Fissured kernels may break upon handling and thus artificially reduce the number of head rice kernels. As reported by Siebenmorgen et al. 2009, milled rice kernels may fissure after very short periods of exposure to air with low relative humidities (less than 30 percent) and/or high temperatures; these conditions would cause rapid moisture loss from kernels. Conversely, fissures can also be created by conditions that cause rapid moisture addition to kernels and are thus associated with high relative humidities (greater than 75 percent) and/or low temperatures. The MC of the rice also plays a role in this moisture gain or loss. While milling is typically conducted at rough rice MCs of approximately 12.5 percent (see below), sometimes samples are supplied at MCs significantly different than this level. In these cases, it is particularly important to be cognizant of the air conditions to which milled rice is exposed. The greater the gradient between the rice MC and the EMC associated with the air, the greater the rate and the extent of kernel fissuring. For example, rice samples with greater MCs will be more susceptible to fissuring in dry-air environments than samples with lesser MCs. The reverse holds true regarding lesser-MC rice samples in very humid environments. Ideally, milled rice fissuring will be minimized or totally prevented if laboratory air relative humidity is maintained between 30 and 75 percent under laboratory temperatures of 70°F. If very low or high laboratory air relative humidities are experienced, milled rice exposure to the air should be minimized. A more complete treatment of this topic, detailing the fissuring rates and extents under a wide range of air temperatures and relative humidities, is provided by Siebenmorgen et al. 2009.

As mentioned previously, a sample's DOM reflects the degree to which bran layers are removed from the brown rice kernel or, conversely, the amount of bran remaining on the milled kernel after milling. This is an important concept, because DOM is known to affect the rice milling yield indices of MRY and HRY, as well as processing characteristics, including cooked rice texture and viscosity parameters. Establishing a target DOM varies with end-use application. For example, ready-to-eat cereal manufacturers typically specify more lightly-milled rice than that used for household cooking applications.

The current FGIS approach to establishing a DOM level of milled rice is to use a classification scale. Based on visual grading, primarily of milled rice kernel color, a sample's DOM is classified as either reasonably well-milled (darkest in color), well-milled, or hard-milled (lightest in color). This classification system is rather subjective and may be skewed by other factors, such as preharvest and postharvest environmental conditions, which can affect kernel color. Instrumental optical or color measurements, such as those obtained by the Satake Milling Meter (Satake Corporation, Hiroshima, Japan), the Kett Whiteness Meter (Kett Laboratory, Tokyo, Japan) or the Hunter Colorflex System (Hunterlab, Reston, Virginia, USA) can minimize subjectivity in color assessment, but to date, instrumental readings have not been standardized to the FGIS DOM categories, nor do they address environmental effects on color.

Surface Lipid Content as a Measure of Degree of Milling

A more objective assessment of DOM can be made by quantifying the surface lipid content (SLC), which is an indication of the amount of bran remaining on milled rice kernels. Because rice bran is approximately 20 percent oil or lipid, measuring the mass of lipid remaining on the surface of kernels after milling indicates the amount of remaining bran. Surface lipid content is the mass percentage of the milled head rice sample that is lipid remaining on the surface of milled rice kernels. As milling progresses and DOM is said to increase, SLC decreases, corresponding to decreasing bran on milled rice kernels. Correspondingly, as SLC decreases, not only bran but also some endosperm is removed and conveyed away in the bran stream, thereby decreasing the mass of milled rice and head rice, which will decrease MRY and HRY.

Surface lipid content may be measured by conventional lipid extraction procedures, such as those using Goldfisch or Soxhlet methods. However, these methods are costly, requiring labor-intensive sample preparation and chemical reagents and do not lend well to online use in a production or high-throughput lab environment. Therefore, much of the rice industry is moving toward more rapid, indirect methods for estimating SLC, the most common of which is near-infrared (NIR) spectroscopy (Saleh, et al. 2008).

During the milling process, there are several factors that influence the degree to which individual kernels, which collectively represent the bulk population of kernels, are milled. Among these are kernel shape characteristics and the MC and temperature of the rice at the time of milling. Additionally, laboratory mill settings can play a large role in determining the

DOM. These factors are discussed in greater detail in the following paragraphs.

Factors That Impact Degree of Milling

There are many factors that impact the rate at which the SLC of a sample decreases as milling progresses, and the consequent effect on MRY and HRY. The **duration that rice is milled** in a laboratory mill is one such factor. Figure 14-1 shows that as milling duration increases, SLC of the head rice decreases, as do MRY and HRY. This is logical because as milling progresses, more of the surface of both head rice and broken kernels is removed, which would decrease the mass of both fractions. The same trend holds true for increasing **pressure within the milling chamber** by increasing the mass attached to the milling lever arm of the mill. Andrews et al. 1992 showed that more pressure applied to the rice in the milling chamber results in more thorough milling, reducing the remaining mass of whole and broken kernels. This study also showed that **initial ample mass**, while having a significant effect on milled rice yields, was not a major factor influencing HRY. It is to be noted, however, that physical limitations of the McGill #2 milling chamber require a rough rice sample size of at least 125 g. Andrews et al. showed that starting with a sample size of only 100 g of rough rice, and thus feeding a brown rice mass of approximately 80 g into the McGill #2 mill, caused a "bottoming out" of the mill lever arm during milling, thus providing insufficient milling action.

The rice MC at the time of milling plays a significant role in the bran removal rate. Several studies have shown that for a set milling duration, as milling MC increases, DOM increases and HRY decreases, since bran is removed at a greater rate as MC increases. An example of this important effect is shown in Figure 14-2, which shows that increasing the MC of rice samples from 9.5 to 14 percent resulted in a HRY reduction ranging from 13 to 17 percentage points, depending on the milling duration. It is to be noted, however, that much of this HRY difference was the result of greater DOM of the greater-MC samples. Reid et al. 1998 and Lanning and Siebenmorgen 2011 also showed that milling MC significantly influenced the rate at which HRY changed with respect to SLC.

Brown rice temperature at the time of milling also impacts bran removal rate. Archer and Siebenmorgen 1995 found that when milling in a McGill #2 mill for set durations, as the initial rice temperature decreased, MRY and HRY increased, indicating greater bran removal resistance, greater SLC levels and correspondingly greater milled rice and head rice masses.

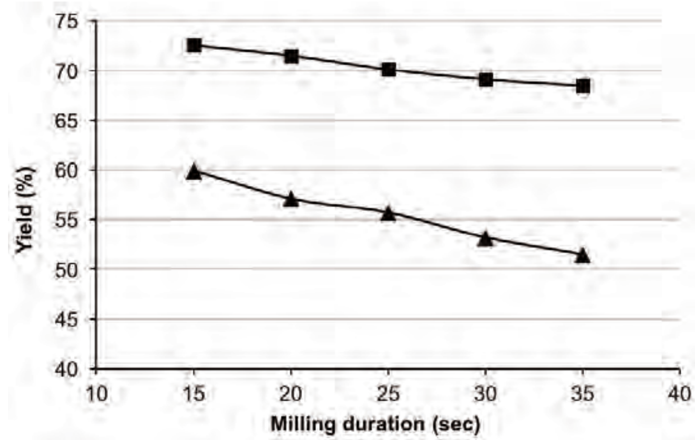


Figure 14-1. Milled rice yields and head rice yields for CL153 rice milled for the indicated durations in a laboratory mill. Also shown are the surface lipid concentrations (SLCs) of each head rice sample.

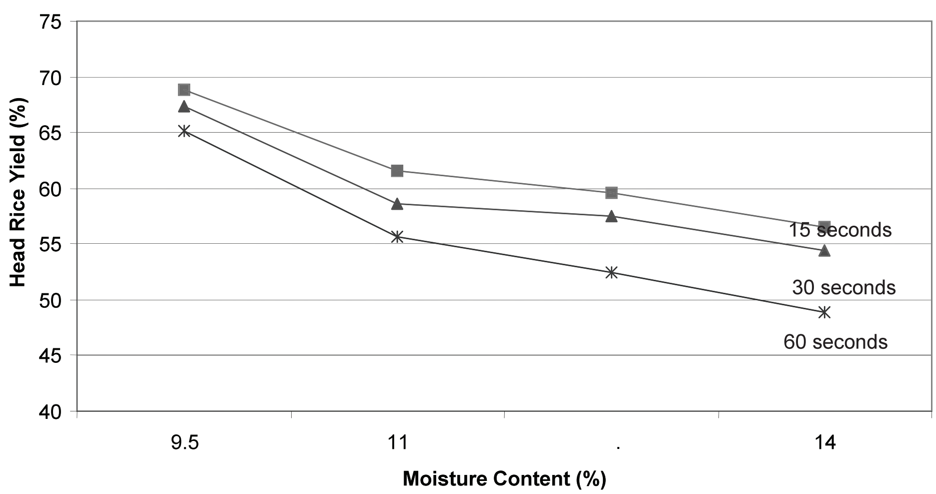


Figure 14-2. Head rice yields attained by milling Newbonnet rice at the indicated moisture contents for the indicated durations. (Source: Andrews et al. 1992)

The differences in milling yield values appeared to be mostly attributable to changes in SLC, since the differences in yields were negated when the milling yield values were adjusted to a constant SLC. Thus, it is recommended to allow laboratory samples to equilibrate to similar temperatures prior to milling.

Additionally, the **rice cultivar or cultivar mix** also affects milling behavior. Rice cultivars inherently differ in physical attributes, including the bran thickness and kernel shape, size and surface topography. These characteristics impact the relative ease with which bran is removed during milling and thus affect the milling duration required to reach a specified DOM/SLC (see relevant articles in the Reference section). For example, cultivars with deep grooves on the kernel surface are likely to have bran remaining in the grooves after milling and, therefore, require more milling pressure or longer milling durations than kernels with smooth surfaces in order to achieve a desired DOM. Milling for longer durations results in greater removal of bran, as well as endosperm, thereby reducing milling yields.

In addition to kernel-surface topography, other cultivar differences can impact milling behavior. It has been reported that hybrid cultivars generally reach a target SLC in a shorter duration than pureline cultivars. "Millability" curves showing first the SLC attained when milled for various durations for the indicated cultivars (Figure 14-3) and secondly the HRYs attained for the various surface lipid contents (Figure 14-4) illustrate differences in milling behavior of cultivars. These differences were attributed to lesser brown rice total lipid content, a presumed indication of a thinner bran layer, as well as greater bran removal rates, in hybrid vs. pureline cultivars.

Figure 14-3 indicates that if milling to a desired SLC of, say, 0.5 percent, Wells required 31 s of milling, whereas XL 723 required only 16 s. Or, alternatively, if a set milling duration of 30 s is used, Wells would be milled to only a SLC of 0.52 percent, whereas XL 723 would be milled to a SLC of 0.29 percent; this difference in milling degree could account for at least

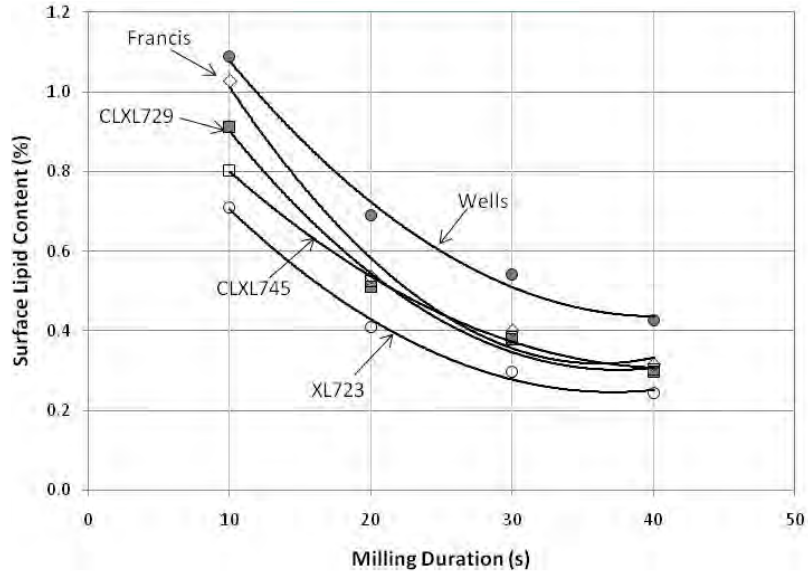


Figure 14-3. Head rice surface lipid contents of Wells, Francis, XL723, CL XL729 and CL XL745 cultivars after milling at rough rice moisture contents of approximately 12.5% (w.b.) for 10, 20, 30 and 40 s using a laboratory mill. Each data point represents the average surface lipid content measured from three replications of each milling duration.

(Source: Lanning and Siebenmorgen, 2011).

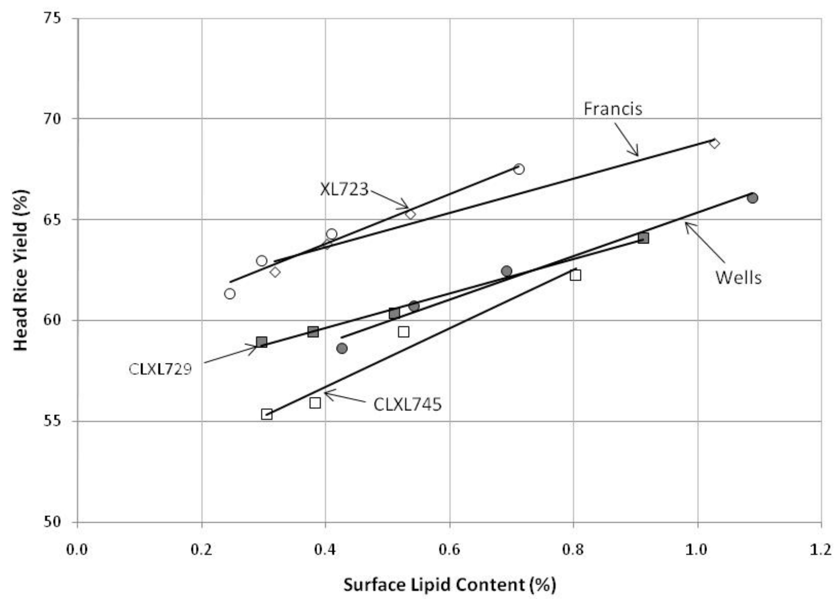


Figure 14-4. Head rice yield vs. head rice surface lipid content of Wells, Francis, XL723, CL XL729 and CL XL745 cultivars milled at rough rice moisture contents of approximately 12.5% (w.b.) for 10, 20, 30 and 40 s using a McGill #2 laboratory mill. Each data point represents the average of three milling replications.

(Source: Lanning and Siebenmorgen, 2011).

2.5 percentage points lower HRY in XL 723 than Wells, just due to having milled XL 723 to a greater extent (see below).

Total lipid content of the brown rice of a cultivar can be impacted by nighttime air temperatures during kernel formation; the greater the nighttime air temperatures during kernel formation, the greater the total lipid content was found to be (Lanning et al. 2012). Thus, year-to-year and location-to-location differences within cultivars can be expected.

Accounting for Degree of Milling When Determining Milling Yield

In assessing milling yield, it is important to have an understanding of how the above variables impact milled rice SLC and, in turn, milling yield. As such, SLC should be measured when conducting laboratory milling analyses in order to equitably compare MRY, HRY, and subsequent milled rice functional properties.

To determine the effect that milling to various degrees has on milling yield of a rice lot, subsamples of the lots can be milled for various durations and the SLC, MRY and HRY measured, providing curves as illustrated in Figures 14-3 and 14-4. Figure 14-3 illustrates the rate at which SLC can change with milling duration and shows that SLC of head rice decreases at an exponential rate with milling duration. In turn, Figure 14-4 shows that HRY is directly and linearly correlated with SLC. The slope of the regression curve can vary among cultivars and lots, depending on the aforementioned variables.

Cooper and Siebenmorgen, 2007, evaluated the millability curves (HRY vs. SLC) of 17 rice lots comprising multiple cultivars, harvest years, harvest locations and storage conditions in an attempt to develop a method for adjusting HRY to account for variation in SLC. Across all lots, the average HRY vs. SLC slope was 9.4; i.e., HRY changed by 9.4 percentage points for every 1.0 percentage point change in SLC. In more practical terms, a decrease of 0.1 percentage points in SLC resulted in a decrease in HRY of 0.94, or nearly 1.0 percentage point. A followup study by Pereira et al. 2008 refined this adjustment method by calculating separate slopes for medium- and long-grain cultivars as 8.5 and 11.3, respectively. That is, for long-grain cultivars, prolonging milling to change the SLC from, say, 0.5 to 0.4 percent would reduce HRY by 1.13 percentage points.

It is typically impractical to produce millability curves for samples from every milling lot being considered. However, it is recommended that the SLC of head rice be measured, and realize that when comparing HRYs of milled samples, SLC levels should be similar and that SLC differences account for HRY differences in the amount of generally 1.1 percentage points of HRY for every 0.1 percentage points of SLC in long-grain cultivars.

Impact of Degree of Milling on End-Use Functionality

Laboratory milling systems are often used to produce representative samples of milled and/or head rice from which functional, sensory and nutritional tests can be performed. As with MRY and HRY, most postmilling properties and processes are impacted by the degree to which rice is milled. Since rice protein and lipid contents are greater in the bran than the endosperm, milling effectively alters the relative proximate composition of the milled kernel by increasing starch content and decreasing protein and lipid contents; the degree to which the composition is altered depends on the DOM. While beyond the scope of this chapter, the reader is referred to articles listed in the Reference section that address DOM impact on rice functional, textural and nutritional properties.

Summary

There are many factors inherent to the rice sample being milled, as well as the laboratory rice mill settings used, that impact the resultant milled rice product. This chapter addresses the effects of many of these factors in determining milling yields. The importance of measuring the DOM of laboratory-milled rice cannot be overstated for allowing equitable comparison of milling yields. The impact of milling to various extents, as measured by SLC, on HRY is detailed.

A considerable advancement in laboratory milling systems could be made by incorporating the means to measure DOM during milling in laboratory mills such that samples could be milled for varying durations to achieve a desired SLC level. This would thus account for varying milling rates produced by rice factors known to impact the rate of bran removal.

References

Many of the following references can be found at http://uarpp.uark.edu.

Ambardekar, A., and T.J. Siebenmorgen. 2012. Effects of postharvest elevated-temperature exposure on rice quality and functionality. *Cereal Chem.* 89 (2): 109-116.

Andrews, S.B., T.J. Siebenmorgen and A. Mauromoustakos. 1992. Evaluation of the McGill #2 rice miller. *Cereal Chem.* 69 (1): 35 43.

Archer, T.R., and T.J. Siebenmorgen. 1995. Milling quality as affected by brown rice temperature. *Cereal Chem.* 72 (3): 304-307.

Billiris, M., T.J. Siebenmorgen, J.F. Meullenet and A. Mauromoustakos. 2012a. Rice degree of milling effects on hydration, texture, sensory and energy characteristics. Part 1. Cooking using excess water. *J. Food Eng.* 113 (4): 559-568.

Billiris, M., T.J. Siebenmorgen and Y. Wang. 2012b. Rice degree of milling effects on hydration, texture, sensory and energy characteristics. Part 2. Cooking using fixed, water-to-rice ratios. *J. Food Eng.* 113 (4): 589-597.

Banaszek, M., T.J. Siebenmorgen and C. Sharp. 1989. Effects of moisture content at milling on head rice yield and degree of milling. *Arkansas Farm Res.* 38 (2): 15.

Bhashyam, M., and T. Srinivas. 1984. Varietal difference in the topography of rice grain and its influence on milling quality. *Journal of Food Science* 49 (2): 393-401.

Chen, H., B.P. Marks and T.J. Siebenmorgen. 1997. Quantifying surface lipid content of milled rice via visible/near-infrared spectroscopy. *Cereal Chem.* 74 (6): 826-831.

Cooper, N., and T.J. Siebenmorgen. 2007. Correcting head rice yield for surface lipid content (degree of milling) variation. *Cereal Chem.* 84 (1): 88-91.

Desikachar, H., S. Rhagavendra Rao and T. Ananthachar. 1965. Effect of degree of milling on water absorption of rice during cooking. *J. Food Sci. Tech.* 2: 110-112.

Lamberts, L., E. De Bie, G. Vandeputte, W. Veraverbeke. V. Derycke, W. De Man and J. Delcour. 2005. Effect of milling on colour and nutritional properties of rice. *Food Chem.* 100 (4): 1496-1503.

Lanning, S.B., and T.J. Siebenmorgen. 2011. Comparison of milling characteristics of hybrid and pureline rice cultivars. *Appl. Eng. Agric.* 27 (5): 787-795.

Lanning, S.B., T.J. Siebenmorgen, A. Ambardekar, P. Counce and R. Bryant. 2012. Effects of nighttime air temperature during kernel development of field-grown rice on physicochemical and functional properties. *Cereal Chem.* 89 (3): 168-175.

Lanning, S.B., and T.J. Siebenmorgen. 2013. Effects of pre-harvest nighttime air temperatures on whiteness of head rice. *Cereal Chem.* (in press).

Matsler, A.L., and T.J. Siebenmorgen. 2005. Evaluation of operating conditions for surface lipid extraction from rice using a Soxtec system. *Cereal Chem.* 82 (3): 282-286.

Perdon, A., T.J. Siebenmorgen, A. Mauromoustakos, V. Griffin, and E. Johnson. 2001. Degree of milling effects on rice pasting properties. *Cereal Chem.* 78 (2): 203-209.

Pereira, T., N. Cooper and T.J. Siebenmorgen. 2008. Effects of storage temperature and duration on the milling properties of rice. *Discovery* 9: 64-74.

Reid, J., T.J. Siebenmorgen and A. Mauromoustakos. 1998. Factors affecting the slope of head rice yield versus degree of milling. *Cereal Chem.* 75 (5): 738-41.

Rohrer, C.A., and T.J. Siebenmorgen. 2004. Nutraceutical concentrations within the bran of various rice kernel thickness fractions. *Biosystems Eng.* 88 (4): 453-460.

Saleh, M., and Meullenet, J.F. 2007. Effect of moisture content at harvest and degree of milling (based on surface lipid content) on the texture properties of cooked long-grain rice. *Cereal Chem.* 84 (2): 119-124.

Saleh, M., J.F. Meullenet and T.J. Siebenmorgen. 2008. Development and validation of prediction models for rice surface lipid content and color parameters using near-infrared spectroscopy: a basis for predicting rice degree of milling. *Cereal Chem.* 85 (6): 787-791.

Siebenmorgen, T.J., A. Matsler and C. Earp. 2006. Milling characteristics of rice cultivars and hybrids. *Cereal Chem.* 83 (2): 169-172.

Siebenmorgen, T.J., M.I. Saleh and R.C. Bautista. 2009. Milled rice fissure formation kinetics. *Trans. of the ASABE* 52 (3): 893-900.

Thompson, J., J. Knutson,and B. Jenkens. 1990. Analysis of variability in rice milling appraisals. *Trans. ASABE* 6 (2): 194-198.

USDA. 2009. *United States Standards for Milled Rice, revised.* Federal Grain Inspection Service. Washington, D.C.

USDA. 2017. *Rice Inspection Handbook.* Federal Grain Inspection Service. Washington, D.C. https://www.gipsa.usda.gov/fgis/handbook/RiceHB/Rice%20Handbook_2017-03-27.pdf.

Chapter

15

Production Factors Impacting Rice Milling Yield

Terry Siebenmorgen, Brandon Grigg, Paul Counce and Jarrod Hardke

Chapter 14 addressed the general procedure for conducting a laboratory milling analysis and factors that impact the measurement of milling yields, specifically milled rice yield (MRY) and head rice yield (HRY). These factors include the rice sample moisture content, temperature and milling ease, as well as laboratory mill settings and the duration for which the rice is milled. The impact of these factors is primarily manifested through variation in the degree to which rice kernels comprising a sample are milled; in turn, the "degree of milling," or DOM, is inversely related to both MRY and HRY.

There are many factors during rice production that can affect milling yield and quality. One such factor is the nighttime air temperature levels during grain filling, which have been correlated to milling yields and to chalkiness, a rice quality index that has received tremendous notoriety in recent years. Chalkiness, illustrated in Photo 15-1, refers to a portion(s) of the kernel endosperm in which starch granules are loosely packed. Minute air spaces between the starch granules of chalky portions alter how light is refracted through the kernel, thus giving a "chalky" vs. "translucent" appearance. High nighttime air temperatures have also been shown to impact many other functional-quality attributes.

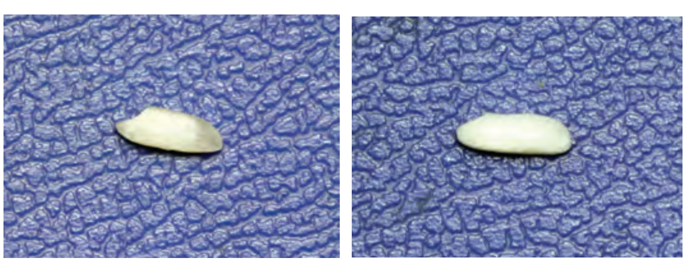


Photo 15-1. Illustrations of chalky kernels. Chalk appears opaque white and may affect a particular region of a kernel (left) or the entire kernel (right).

Another production factor that is strongly associated with rice milling yields is the moisture content (MC) at which rice is harvested. The MC of rice at harvest is an indicator of the prevalence of immature kernels at high harvest MCs and the percentage of fissured kernels at low harvest MCs.

The physical strength of a kernel ultimately determines its ability to withstand the rigors of postharvest processing without breaking apart. Kernels that are chalky, fissured, immature or otherwise physically damaged generally have reduced mechanical strength relative to nondamaged kernels. These damaged kernels are less likely to withstand the aggressive actions of dehulling and milling, resulting in a greater percentage of broken kernels produced in the milling process. Head rice yield, the mass percentage of kernels that remain intact (head rice) relative to the initial quantity of rough rice, is a primary driver of the economic value of a rice lot; please also see Chapter 14.

Nighttime Air Temperature

The physiological processes leading to deleterious nighttime air temperature impacts are not completely understood. However, the general premise is that abnormally high ambient nighttime air temperatures during kernel formation (reproductive stages R5-R8) disrupt the starch formation process within the developing kernel. Thus, starch structure is altered and the general packing density of starch granules is reduced, creating chalky portions of kernels with associated changes in physicochemical properties.

Previous research conducted in controlled-air chambers has shown that increasing nighttime air temperatures (defined as those occurring between 8 p.m. and 6 a.m.) during certain kernel reproductive stages was strongly correlated to increasing levels of chalkiness and reduced HRYs, but the degree of susceptibility was cultivar-dependent. To test these findings in commercial practice, field data were collected from six cultivars grown in 2007 through 2010 at locations from northern to southern Arkansas. The 95th percentile of nighttime air temperatures was used to represent the temperature below which 95 percent of nighttime air temperatures occurred during a reproductive stage. It is noted that the data from 2010 generally represented extreme nighttime air temperatures for the U.S. Mid-South, with historically high chalk levels and low HRYs. Figure 15-1, from this study, illustrates that, in general, as nighttime air temperatures during the R-8 reproductive stage increased, chalk values increased and HRYs correspondingly decreased dramatically, particularly in some cultivars.

The most dramatic impact on milling yield is that peak HRYs, associated with harvest MC levels corresponding to maximum milling yield (see below), can be reduced substantially when high nighttime air temperatures occur during grain filling. This effect can help explain previously inexplicable differences in milling yield. Figure 15-2 provides such an example, in which peak HRYs of the same cultivar, grown during 2008 at two Arkansas locations (Pine Tree in the northern and Stuttgart in the southern parts of the state), were as much as four percentage points different; this difference was attributed to the effect of higher nighttime air temperatures during R8 at Stuttgart.

Of additional note, strong correlations between many compositional/functional properties and nighttime air temperatures during kernel development were noted as part of the above study. Of particular relevance to milling characteristics, brown rice total lipid content, reasoned to be an indicator of the thickness of overall rice kernel bran layers, was shown to linearly increase with increasing nighttime air temperatures, thus impacting the duration required to mill kernels to a specified DOM level. This not only affects the throughput of commercial mills, but also impacts laboratory assessment of milling yield and the equitable comparison of HRYs among samples; please see Chapter 14.

This recent research has shown, at both laboratory and field levels, that HRY is inversely affected by nighttime air temperatures during the grain filling stages of reproductive growth. The research has also shown that the effects of nighttime air temperatures reach beyond milling yields and may be responsible for inexplicable processing variability sometimes purported in Mid-South rice.

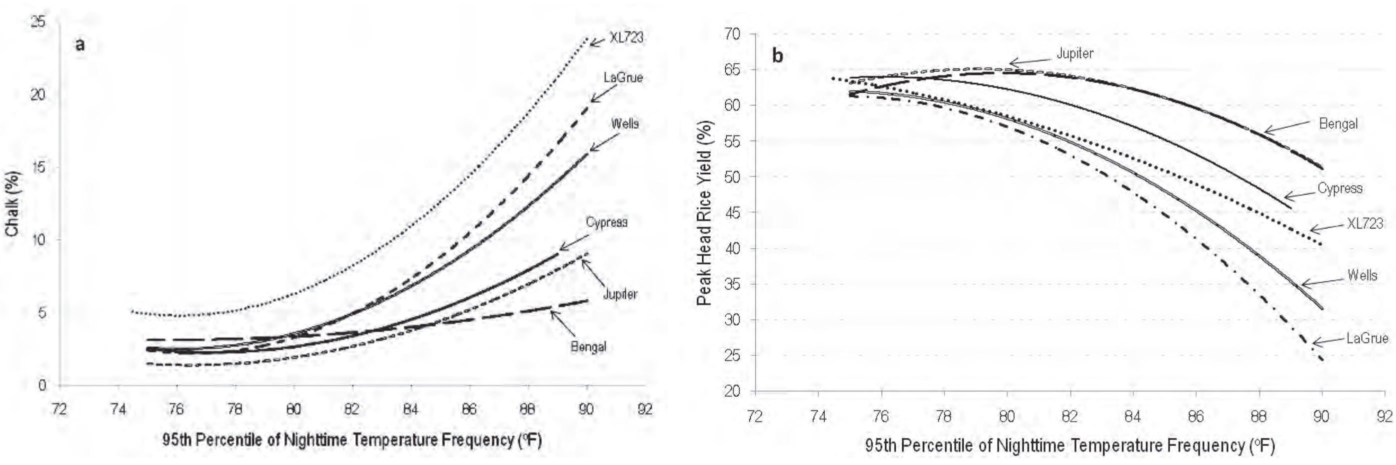


Figure 15-1. Relationships of chalk (a) and peak head rice yields (b) and the 95th percentiles of nighttime air temperature frequencies during the R8 stages of the indicated cultivars grown during 2007, 2008, 2009 and 2010.
Source: Lanning et al., 2011.

Harvest Moisture Content

Head rice yield typically varies with the MC at which rice is harvested. Research in Arkansas has reported that the peak HRY, under Arkansas weather conditions, is attained at a harvest MC of approximately 19 to 21 percent for long-grain cultivars and 22 to 24 percent for medium-grains. Reports from Texas indicate that HRY peaked shortly after "maturity" and declined sharply thereafter. Harvesting at MCs greater than or less than optimal can result in decreased HRY, as illustrated in Figure 15-3; the causes are explained as follows.

As rice matures, kernels on a panicle exist at very different MCs, representing various maturity and kernel strength levels. An example of this is illustrated in Figure 15-4, which shows that a large spread in individual kernel MCs of 'Bengal' medium-grain rice existed when the average, bulk MC was 22.7 percent. Additionally, the distribution of individual kernel MCs on panicles changes as the bulk MC of a sample changes. For example, individual kernel MC distributions usually have multiple "peaks" when rice is harvested at 16 percent MC or greater, but generally have a single peak at lesser MCs. At lower bulk MCs, there is usually only a single peak, yet there is typically still a large range in kernel-to-kernel MCs, as is shown in Figure 15-4, for rice at a bulk MC of 14.3 percent. Thus, at any given point in time during the harvest season, some kernels on a panicle may be at much different MC than others and thus will respond differently to ambient air changes.

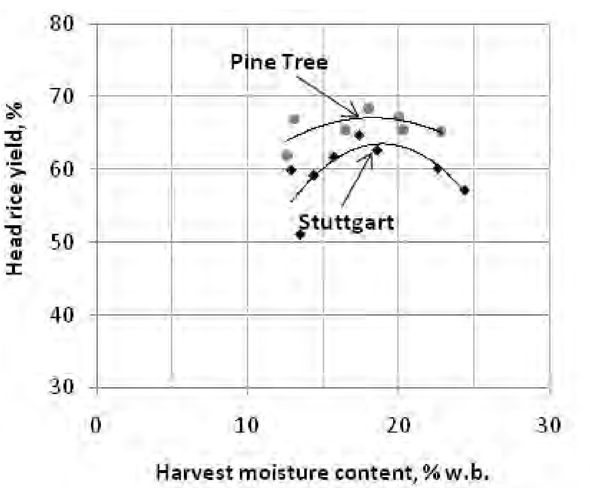


Figure 15-2. Difference in head rice yields of long-grain cultivar Wells harvested over a range of moisture contents at northern (Pine Tree) and southern (Stuttgart) locations in Arkansas during 2008. The difference in peak head rice yields between the two lots is attributed to elevated nighttime air temperatures that were observed in Stuttgart during the grain-filling stages compared to Pine Tree.

Individual kernel MC distributions can be used to explain milling yield changes throughout a harvest season by indicating the percentage of "immature" kernels, often considered as those kernels with MCs greater than 22 percent, as well as the percentage of

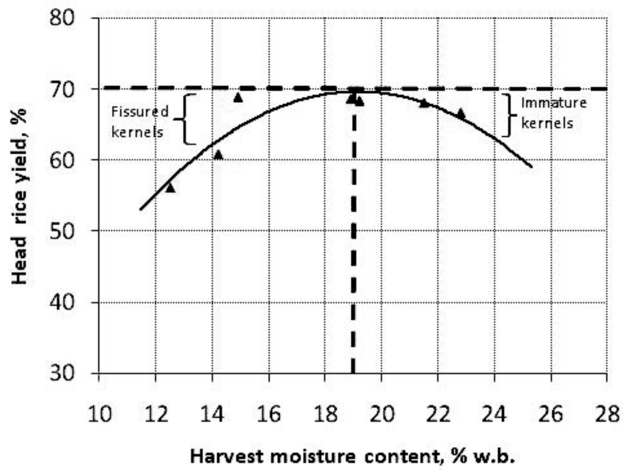


Figure 15-3. Parabolic relationship between head rice yield and harvest moisture content of long-grain cultivar Cypress sampled over a range of harvest moisture contents from Keiser, Arkansas.

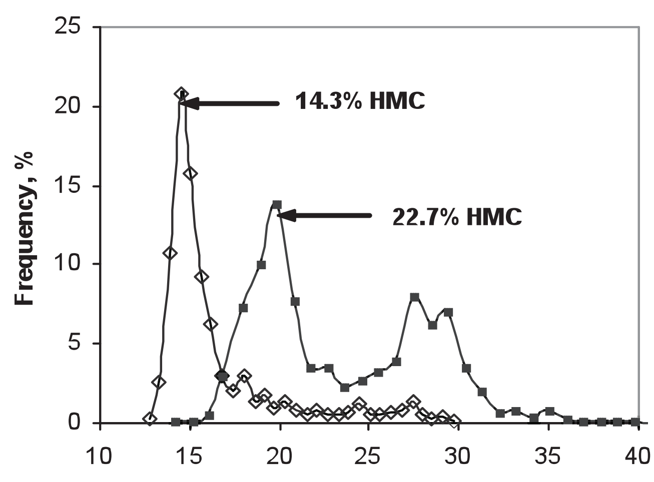


Figure 15-4. Individual kernel moisture content distributions within panicles (composite of kernels from five panicles) of Bengal rice at average harvest moisture contents (HMCs) of 22.7% and 14.3% from Stuttgart, Arkansas.

Source: Bautista and Siebenmorgen, 2005.

"dry" kernels, often taken as those kernels with MCs less than 14 percent. Immature kernels, illustrated in Photo 15-2, can be a source of milling yield reduction due to the fact that these kernels are typically weak in structure and often break during milling. Rapid rewetting of low-MC kernels, such as would occur through exposure to rain or ambient air relative humidities greater than approximately 80 to 85 percent, typically cause dry kernels to expand rapidly at the kernel surface. However, because an extended duration is required for the moisture to migrate inward, the kernel center cannot immediately expand, creating stress differentials from the kernel surface to the core that ultimately result in material failure and fissures. Fissured kernels, as illustrated in Photo 15-3, typically break apart during milling, drastically reducing HRY.

Figure 15-5 shows that the percentage of fissured kernels in samples increases approximately exponentially as the MC at which rice is harvested decreases. As rice dries in the field, the percentage of kernels with MCs less than 14 percent increases dramatically (Figure 15-6), thus exposing increasing numbers of dry kernels to rapid moisture adsorption conditions. The propensity for kernels to fissure due to moisture adsorption increases as the kernel MC decreases. It is to be noted that the rate of fissured kernel percentage increase (Figure 15-5) is not always perfectly correlated to the percentage of low MC kernels, since fissuring by moisture adsorption is dependent on moisture being supplied by the environment in some manner, such as precipitation or high relative humidity air.

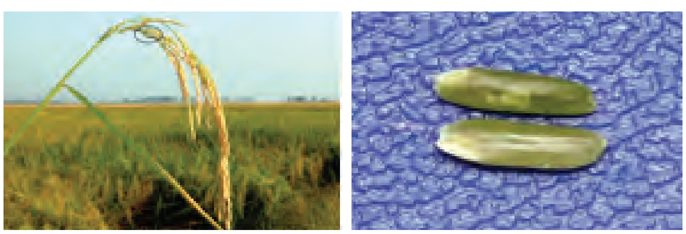


Photo 15-2. Illustration of immature kernels, on the panicle (left) and after harvest and hulling (right), which are generally weak in structure and prone to breaking.

Photo 15-3. Illustration of a kernel fissured due to rapid moisture adsorption.

An example of the relationship between HRY and individual kernel MC distributions is given in Figure 15-6. The HRY versus harvest-MC curve of Figure 15-6 indicates a peak HRY at approximately 20 percent harvest MC. The decline in HRY at low harvest MCs corresponds to the increasing percentage of kernels with MCs less than 14 percent; such kernels would likely be fissured due to rapid moisture adsorption.

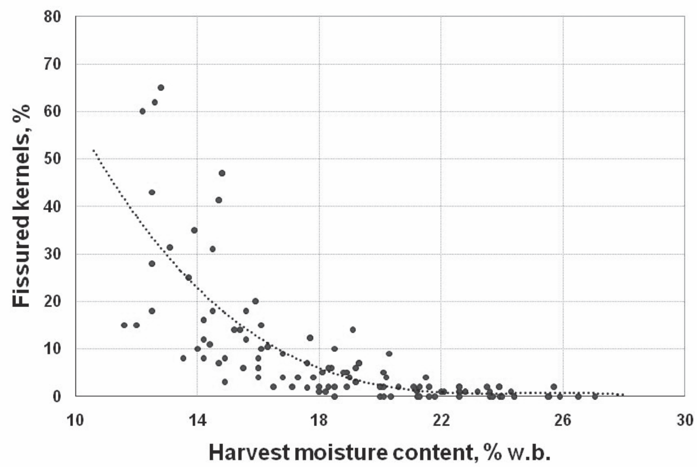


Figure 15-5. Fissured kernel percentages as a function of harvest moisture content.

Source: Bautista et al., 2009.

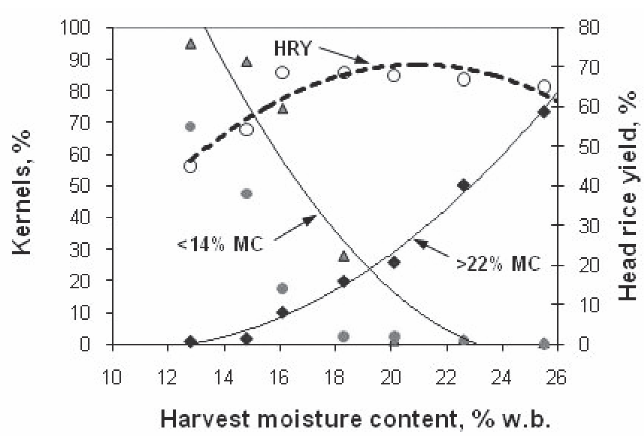


Figure 15-6. Relationships of percentages of kernels at moisture contents (MCs) >22% or <14% and head rice yields (HRYs) to harvest MCs for long-grain cultivar Drew harvested at Keiser, Arkansas.

Source: Bautista et al., 2009.

It is noted that in some cases, very good HRYs have been reported even when rice was harvested at relatively low MCs. Though this is sometimes possible, due to lack of precipitation and low relative humidities during the harvest season, it is not the long-term rule. If rice is allowed to dry in the field to MCs less than 14 to 15 percent, a short period of aggressive moisture adsorption conditions prior to harvest can rapidly and dramatically decrease HRYs.

Figure 15-6 also shows that HRYs of long-grain rice decline at harvest MCs greater than the peak of 20 percent. This is likely due to the increasing presence of thin, immature kernels, illustrated in Figure 15-6 by the curve depicting the percentage of kernels with MCs greater than 22 percent. Research has shown that these thin kernels often break during milling.

Trends in HRY across harvest MCs were studied over a five-year period for multiple cultivars and locations in Arkansas. Most of these trends were parabolic in form, similar to that indicated in Figure 15-6. Such trends allowed the harvest MC at which HRY peaked to be estimated. It is from this study that the optimum harvest MC for maximizing HRY was reported to be 19 to 21 percent for long-grain cultivars and 22 to 24 percent for medium-grains, under Arkansas weather conditions. Of confirming note is that for California conditions, recommendations call for harvesting medium-grain cultivars at MCs greater than 21 percent.

Based strictly on maximizing HRY, it is generally recommended to harvest rice at these optimal MCs. However, when considering that drying costs generally increase dramatically with harvest MC, the economic optimum harvest MC may be slightly less than the optimal MC for maximizing HRY, depending on drying charges and the relative value of head rice to brokens. Please see the relevant article in the References.

Other Production Factors

Other production factors can also impact milling yield and quality. For example, diseases such as rice blast can cause milling yield reductions. Candole et al. 2000 reported that blast reduced HRYs by 7 and 12 percentage points in a long-grain and medium-grain cultivar, respectively, grown in Arkansas. Kernel smut disease anecdotally reduces milling yield and can sufficiently discolor rough rice to create quality reductions during parboiling. Field insects can also have detrimental effects on rice quality. Most notable is the stink bug, which bores into the kernel during development, resulting in a black spot on the kernel known as "peck." Such kernels are typically removed after milling using color sorters.

The amount and timing of nitrogen fertilizer applied to rice during growth can impact milling yields. Greater nitrogen application rates at the beginning of kernel development are generally considered to increase HRY. One researcher surmised that a decline in HRY associated with reduced nitrogen application was a result of either decreased integrity of protein structural components of the rice kernel or of faster maturation and drying. Other data shows that top-dressing nitrogen fertilizer at heading resulted in increased protein content for all cultivars tested and increased HRY for four of five cultivars evaluated, with the outlier being a cultivar with known high HRY potential.

Summary

In summary, any factor that causes a reduction in the strength of kernels, and consequently the ability of kernels to withstand the forces imparted during hulling and milling, will impact milling yield. In this chapter, high nighttime air temperatures during grain filling and the moisture content at which rice is harvested are detailed in terms of impact on milling yield. Other production factors, including diseases and nitrogen application rates, can also have significant impacts on milling yields and quality. All of these factors can have milling yield implications, with their mode of impact being different. For example, nighttime air temperatures during grain filling can produce kernel chalkiness, which reduces kernel strength. Additionally, harvesting at very high MCs can produce large percentages of thin, immature kernels, whereas at low MCs, large percentages of fissured kernels can result from rapid moisture adsorption; both factors dramatically reduce kernel strength. Because of the importance of milling yields in the rice industry, these production factors can have significant implications in terms of economic value.

References

Many of the following references can be found at http://uarpp.uark.edu.

Ahmad, S., M. Zia-Ul-Haq, H. Ali, A. Ahmad, M.A. Khan, T. Khaliq, Z. Husnain, A. Hussain and G. Hoogenboom. 2009. Morphological and quality parameters of *Oryza sativa* L. as affected by population dynamics, nitrogen fertilization and irrigation regimes. *Pak. J. Bot.* 41 (3): 1259-1269.

Ambardekar A.A., T.J. Siebenmorgen, P.A. Counce, S.B. Lanning and A. Mauromoustakos. 2011. Impact of field-scale night-time air temperatures during kernel development on rice milling quality. *Field Crops Res.* 122 (3): 179-185.

Bautista, R.C., and T.J. Siebenmorgen. 2005. Individual rice kernel moisture content variability trends. *Applied Engineering in Agriculture* 21 (4): 637-643.

Bautista, R.C., T.J. Siebenmorgen and A. Mauromoustakos. 2009. The role of rice individual kernel moisture content distributions at harvest on milling quality. *Trans. of the ASABE* 52 (5): 1611-1620.

Calderwood D.L., C.N. Bollich and J.E. Scott. 1980. Field drying of rough rice: effect on grain yield, milling quality and energy saved. *Agrononomy Journal* 72: 649-653.

Candole, B., T.J. Siebenmorgen, F. Lee and R. Cartwright. 2000. Effect of rice blast and sheath blight on the physical properties of selected rice cultivars. *Cereal Chemistry* 77 (5): 535-540.

Chau, N.N., and O. R. Kunze. 1982. Moisture content variation among harvested rice grains. *Trans. of the ASAE* 25 (4): 1037-1040.

Cooper, N.T.W., T.J. Siebenmorgen and P.A. Counce. 2008. Effects of nighttime temperature during kernel development on rice physicochemical properties. *Cereal Chemistry* 85 (3): 276-282.

Counce, P.A., T.C. Keisling and A.J. Mitchell. 2000. A uniform, objective and adaptive system for expressing rice development. *Crop Sci.* 40: 436-443.

Counce, P.A., R.J. Bryant, C.J. Bergman, R.C. Bautista, Y.J. Wang, T.J. Siebenmorgen, K.A.K. Moldenhauer and J.F. Meullenet. 2005. Rice milling quality, grain dimensions and starch branching as affected by high night temperatures. *Cereal Chemistry* 82: 645-648.

Dilday, R.H. 1988. Effect of nitrogen fertilizer on milling quality of rice (*Oryza sativa*). *Proc. Arkansas Acad. Sci.* 42: 26-27.

Ghosh, M., B.K. Mandal, B.B. Mandal, S.B. Lodh, and A.K. Dash. 2004. The effect of planting date and nitrogen management on yield and quality of aromatic rice (*Oryza sativa*). *Journal of Agricultural Science* 142: 183-191.

Lanning S.B., and T.J. Siebenmorgen. 2011. Comparison of milling characteristics of hybrid and pureline rice cultivars. *Applied Engineering Agriculture* 27 (5): 787-795.

Lanning S.B., T.J. Siebenmorgen, P.A. Counce, A.A. Ambardekar and A. Mauromoustakos. 2011. Extreme nighttime air temperatures in 2010 impact rice chalkiness and milling quality. Field Crops Res. 124 (1):132-136.

Lanning, S.B., T.J. Siebenmorgen, A.A. Ambardekar, P.A. Counce and R.J. Bryant. 2012. Effects of nighttime air temperature during kernel development of field-grown rice on physicochemical and functional properties. *Cereal Chemistry* 89 (3): 168-175.

McClung, A.M. 2004. The rice plant: Growth, development and genetic improvement. Chapter 2. In: *Rice Chemistry and Technology, Third Ed.* E.T. Champagne, editor. American Association of Cereal Chemists, Inc. St. Paul, Minnesota.

Mutters, R., and J. Thompson. 2006. Effect of weather and rice moisture at harvest on milling quality of California medium-grain rice. *Trans. of the ASABE* 49 (2): 435-440.

Nangju, D., and S.K. De Datta. 1970. Effect of time of harvest and nitrogen level on yield and grain breakage in transplanted rice. *Agronomy Journal* 62: 468-474.

Perez, C.M., B.O. Juliano, S.P. Liboon, J.M. Alcantara and K.G. Cassman. 1996. Effects of late nitrogen fertilizer application on head rice yield, protein content and grain quality of rice. *Cereal Chemistry* 73 (5): 556-560.

Seetanum W,. and S.K. De Datta. 1973. Grain yield, milling quality and seed viability of rice as influenced by time of nitrogen application and time of harvest. *Agronomy Journal* 65: 390-394.

Siebenmorgen, T.J., R.C. Bautista and J.-F. Meullenet. 2006. Predicting rice physicochemical properties using thickness fraction properties. *Cereal Chemistry* 83 (3): 275-283.

Siebenmorgen, T.J., R.C. Bautista and P.A. Counce. 2007. Optimal harvest moisture contents for maximizing milling quality of long- and medium-grain rice cultivars. *Applied Engineering in Agriculture* 23 (4): 517-527.

Siebenmorgen, T.J., N.T.W. Cooper, R.C. Bautista, P.A. Counce, E. Wailes and K.B. Watkins. 2008. Estimating the economic value of rice (*Oryza Sativa* L.) as a function of harvest moisture content. *Applied Engineering in Agriculture* 24 (3): 359-369.

Tashiro, T., and I.F. Wardlaw. 1991. The effect of high temperature on kernel dimensions and the type and occurrence of kernel damage in rice. *Australian J. Ag. Res.* 42 (3): 485-496.

Chapter

16

Fundamentals of On-Farm Rice Drying and Storage

Sammy Sadaka and Jarrod Hardke

Arkansas rice producers are increasingly adopting the use of on-farm drying and storage facilities. Quality is the major factor affecting the market value of rice, and proper management of rice dried and stored on-farm is essential to maintaining high quality rice. Immediately following harvest, rice quality is typically at its peak. The final quality of rice ready to market is sensitive to all post-harvest processes, such as drying, handling, storage and milling. On-farm rice drying and storage has the potential to increase harvest efficiency, reduce harvesting delays and provide more control over grain quality, all of which contribute to overall market/delivery time flexibility.

Management Key

Follow the "50-50 Rule" and do not attempt to dry grain when the temperature is below 50 degrees or when the humidity is above 50 percent.

Tips for Rice Drying

The goal of rice drying is to reduce grain moisture content to meet the recommended levels for safe, long-term storage. When placed in storage, rice should be dried quickly to a moisture level of about 12 percent to minimize any quality deterioration. Rice drying can be accomplished in bins by blowing large volumes of dry air through the grain (Photo 16-1).

The flow rate and the quality of this air determine the drying duration and the final moisture content of the rice kernels. Air quality typically refers to the equilibrium moisture content (EMC) achievable under the conditions of the air. (Table 16-1). If the EMC of air is 12 percent, then rice moisture will eventually reach 12 percent. It is important to know that a given volume of air has the capability of holding a given amount of moisture. The amount of moisture a volume of air can hold depends on its quality.

Photo 16-1. Grain drying facility.

Therefore, it is possible to increase the drying rate, or force the grains to reach equilibrium with air sooner, by passing larger amounts of air over the grain. High volumes of air are needed to carry the moisture away

Table 16-1. Long-grain rice equilibrium moisture content.

	Relative Humidity (%)													
Temperature	25	30	35	40	45	50	55	60	65	70	75	80	85	
35	9.2	10.1	10.9	11.7	12.5	13.3	14.1	14.9	15.7	16.6	17.6	18.6	19.8	21.3
40	9.0	9.9	10.7	11.5	12.3	13.0	13.8	14.6	15.4	16.3	17.2	18.2	19.4	20.9
45	8.8	9.7	10.5	11.2	12.0	12.8	13.5	14.3	15.1	15.9	16.9	17.9	19.0	20.5
50	8.6	9.5	10.3	11.0	11.8	12.5	13.3	14.0	14.8	15.7	16.5	17.5	18.7	20.1
55	8.5	9.3	10.1	10.8	11.5	12.3	13.0	13.8	14.5	15.4	16.3	17.2	18.4	19.8
60	8.3	9.1	9.9	10.6	11.3	12.1	12.8	13.5	14.3	15.1	16.0	16.9	18.1	19.5
65	8.2	8.9	9.7	10.4	11.1	11.9	12.6	13.3	14.1	14.9	15.7	16.7	17.8	19.2
70	8.0	8.8	9.5	10.3	11.0	11.7	12.4	13.1	13.8	14.6	15.5	16.4	17.5	18.9
75	7.9	8.7	9.4	10.1	10.8	11.5	12.2	12.9	13.6	14.4	15.2	16.2	17.2	18.6
80	7.8	8.5	9.2	9.9	10.6	1.3	12.0	12.7	13.4	14.2	15.0	15.9	17.0	18.3
85	7.6	8.4	9.1	9.8	10.5	11.1	11.8	12.5	13.2	14.0	14.8	15.7	16.8	18.1
90	7.5	8.3	9.0	9.6	10.3	11.0	11.6	12.3	13.0	13.8	14.6	15.5	16.5	17.8
95	7.4	8.1	8.8	9.5	10.2	10.8	11.5	12.2	12.9	13.6	14.4	15.3	16.3	17.6
100	7.3	8.0	8.7	9.4	10.0	10.7	11.3	12.0	12.7	13.4	14.2	15.1	16.1	17.4

in a timely fashion when rice is at high moisture levels. Doubling the airflow will typically cut the drying time to about half. It is also possible to add heat to condition the air to a desirable EMC – or to maintain the same level available during the daylight hours. If the EMC of air is greater than 12 percent, then it will not be possible to reduce rice moisture to 12 percent. In this situation, the air can be heated to reduce the EMC to 12 percent. While heating the air typically reduces its EMC and increases its moisture-holding capacity, it is important to consider the added cost to the drying process. Airflow rates for drying vary from a low of 1 cubic foot per minute (CFM) per hundredweight (cwt) to a high of 100 or more CFM per cwt. The recommended minimum airflow rates for different moisture contents levels are shown in Table 16-2.

Management Key

One way to reduce drying time is to increase airflow, but this may not be the most energy efficient manner of drying.

Air may be delivered to the drying bin by a centrifugal fan or an axial flow fan. Manufacturers provide several models of these fans to meet the needs of field applications. The two critical characteristics of fans are flow rate (CFM) and static pressure expressed in inches of water.

Table 16-2. Recommended minimum airflow rates for different moisture content levels.

Moisture Content	Airflow Rate
%	CFM†
13-15	1-2
15-18	4
18-20	6
20-22	8
> 22	12

† Cubic foot per minute per cwt.

The axial fan (Photo 16-2) utilizes a propeller wheel mounted directly to the motor shaft; thus, it develops a very high tip speed and is often noisy. Axial fans are cheaper and are most often used where high airflow rates, at low static pressures, are needed.

Centrifugal fans (Photo 16-3) provide a relatively constant air volume over a wide range of static pressures. Centrifugal fans are more expensive than axial fans and can be purchased as a direct-driven or a belt-driven unit. Belt-driven units are more expensive but have a greater life expectancy. Centrifugal fans are highly recommended where high static pressures and less noise are needed.

Practically, most on-farm bins have limited available air capacity. As grain bins are filled and the grain depth increases, it becomes more difficult to move air up through the grain. Additionally, less air will be

Photo 16-2. Axial fan.

Photo 16-3. Centrifugal fan.

available for each bushel of grain in the bin as it becomes full. This is why, initially, bins should not be completely filled with high moisture content grain. Once grain moisture reaches 15 percent or less throughout the bin, the bin filling process may be completed. However, care should be taken not to mix dry grain (less than 15 percent moisture) with moist grain (greater than 18 percent moisture). The reason is that any rewetting after the rice kernel is dried to a level below 15 percent may cause excessive fissuring

Management Key

Dry high moisture rice in shallow depths until 15 percent moisture or less, then deeper depths can be dried.

and reductions in head rice yield (HRY). Rewetting may also occur if moist air is pumped through the grain.

The EMC can be determined by measuring the air temperature and relative humidity. Thermometers, or temperature sensors, are typically used to determine the temperature, while the relative humidity is usually determined by using a sling psychrometer. Sling psychrometers (Figure 16-1) are relatively inexpensive, and they work by first measuring the air temperature with a wet and dry bulb thermometer and then determine relative humidity using a table. One should strive to maintain a steady EMC that is very close to the storage moisture content. There are typically numerous days during the harvest season when the EMC is at, or below, the desired level without adding any heat.

Figure 16-1. Sling psychrometer.

As mentioned earlier, it may be necessary to add some heat to condition the air to a desirable EMC during night or damp weather conditions. If heat is not available, it may be better to turn the fans off at night instead of pumping in moist air. Pumping in air at night may actually add moisture to the bin that will have to be removed later. This increases drying costs and may result in significant HRY reductions. Fans should be turned off almost any time the EMC of the air is greater than that of the grain. The exception might be for very damp rice – to avoid heat buildup.

Management Key

Exercise extreme caution when drying air temperature exceeds 100°F.

As the bin is being filled, grain should not be allowed to cone. If coning occurs, the large particles will migrate to the outside and small particles (flour and trash) will remain at the center of the cone

(Figure 16-2). This results in a non-uniform distribution of voids among the grains, which leads to uneven air flow distribution through the grain. Most of the air will pass up the outside of the bin through the larger and cleaner grain. A level height should be maintained throughout the filling process. Once the separation occurs, it is hard to remedy later – even if the bin is later shoveled level.

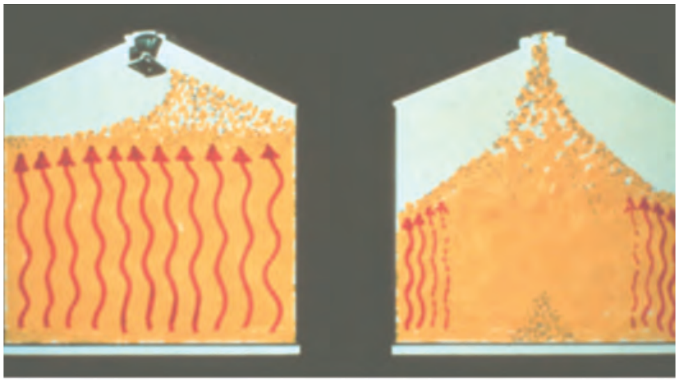


Figure 16-2. Grain bin filling and coning.

A stirring method is needed in grain drying as well. Stirring facilitates the drying process by lifting grain from the bottom to the top. It also facilitates aeration and removes hot spots; therefore, it helps maintain grain in store and speeds the drying process. Stirring also makes the grain flow extremely well which improves grain handling. This loosens the grain so that additional air may be moved up through the grain. On the other hand, there is a concern among some producers that the stirring may grind away the rice if left on. There is no research evidence to support this concern. There will usually be a small amount of flour-like substance formed around the auger's top.

Tips for Rice Storage

Once rice has been successfully dried to about 12.5 percent moisture throughout the storage container, the bin can be filled and the surface leveled. After this has been accomplished, aeration is needed to limit the amount of heat generated by bulk stored rice. Aeration with ambient (outside) air may be needed for the next few weeks, but only when humidity is below 60 percent and the air temperature is 50 to 60°F. Do not operate fans when air temperatures are below 32°F.

Bulk rice stored in bins should be monitored at least once a week for variation in temperature or moisture. Moisture migration can occur in bins with improper temperature control and can result in deterioration or spoilage of kernels. Periodic aeration may be necessary to counter extreme temperature changes during storage.

Additional information on rice drying and storage can be found here: https://www.uaex.edu/farm-ranch/crops-commercial-horticulture/Grain_drying_and_storage/rice_drying_and_storage.aspx.

Chapter

17

Rice Research Verification Program

Jarrod Hardke, Brad Watkins, Ralph Mazzanti and Ron Baker

In 1983, the University of Arkansas Division of Agriculture Cooperative Extension Service established an interdisciplinary rice educational program to emphasize management intensity and integrated pest management to maximize returns. The Rice Research Verification Program (RRVP) was implemented to verify the profitability of University of Arkansas recommendations in fields with less than optimum yields or returns.

Since 1983, the RRVP has been conducted on 462 commercial rice fields totaling 26,827 acres. The RRVP is funded by rice grower check-off contributions administered by the Arkansas Rice Research and Promotion Board. The Arkansas RRVP represents a public exhibition of the implementation of research-based Extension recommendations in an actual field-scale farming environment. Through this program, farmers have increased yields, reduced input costs and increased net returns. The yield of fields enrolled in the RRVP has averaged 18 bushels per acre greater than the state average.

Program Goals

1. To demonstrate to producers that University of Arkansas rice management recommendations developed from small-plot research are applicable to large-scale field applications and provide optimum yields and economic returns.
2. To evaluate the current University of Arkansas rice management recommendations for completeness and determine where weaknesses in knowledge or information exist and further research is warranted.
3. To train new county extension agents in rice production and provide experiences that will benefit the agent in his overall county programming with respect to rice production.

Program Objectives

- To conduct on-farm field trials to verify the utility of research-based recommendations with the intent of optimizing the potential for profits.
- To develop an on-farm database for use in economic analyses and computer-assisted management programs.
- To aid researchers in identifying areas of production that require further study.
- To improve or refine existing recommendations which contribute to profitable production utilizing all production systems applicable to the commodity.
- To increase county extension agents' expertise in the specified commodity.
- To utilize and incorporate data and findings from the Research Verification Program into extension educational programs at the county and state level.
- To enhance the rice production skills and knowledge of program cooperators.

Program Summary

Each year, University of Arkansas rice production recommendations are evaluated on RRVP fields seeded in different cultivars, cultural practices and environmental conditions. Information is gathered through data collected from each field as a whole as well as small replicated plots within the fields. This agronomic information is used to improve and refine recommendations to meet the needs of Arkansas rice farmers and identify areas which need additional research.

Farm cooperators agree to pay production expenses, provide crop expense data for economic analysis, scout the field with the coordinator and county agent on a weekly basis and implement recommended production practices in a timely manner from seedbed preparation to harvest. A designated county extension agent from each participating county assists the RRVP coordinator in obtaining field background information, keeping records on the field and maintaining regular contact with the grower. The agent is also responsible for scouting the field twice each week to evaluate field conditions and pest thresholds. Management decisions are made by the RRVP coordinator based on the current University of Arkansas recommendations during weekly field inspections. Technical assistance is provided by the appropriate extension specialist or researcher as needed.

Economic information is collected on the RRVP fields to estimate crop expenditures and returns. Selected yield and economic information is presented for the period 2006 through 2017 in Tables 17-1, 17-2 and 17-3. Good yields in the RRVP have enabled participants to achieve acceptable returns (Table 17-1). Average RRVP yields for the 2006-2017 period were 178 bushels per acre (Table 17-1), compared with state average yields of 158 bushels per acre for the same period (Table 17-2). In 2007 and 2013, the program achieved its highest yield since the establishment of the program at 191 bushels per acre, which was 30 bushels per acre over the reported state average.

Despite high production expenses, participants tend to receive high returns. The average return above total expenses for the RRVP was $353.42 per acre, while total expenses (operating plus ownership) averaged $635.39 per acre during 2006-2017 (Table 17-1). This compares with a state average return above total expenses of $160.01 per acre and state average total expenses of $712.15 per acre for the same period (Table 17-2). The average break-even price (total expenses divided by average grain yield) for the RRVP program during 2006-2017 was $3.57 per bushel (Table 17-1), compared with a state average break-even price of $4.53 per bushel over the same period (Table 17-2). These numbers indicate that average returns to the RRVP program were above state average returns during most years, and these higher returns were due in large part to higher yields and lower total expenses on average. Additional information on

Table 17-1. Economic information of RRVP fields, 2006-2017.

Year	Average Arkansas Rice Price†	RRVP Average Grain Yield‡	Total Operating Expenses††	Ownership Expenses††	Total Expenses	Returns Above Total Expenses	Breakeven Price
	$/bu	Bu/A	$/A	$/A	$/A	$/A	$/bu
2006	4.11	164	396.40	44.45	440.85	233.19	2.69
2007	4.65	191	438.92	51.25	490.17	397.14	2.57
2008	7.43	174	668.00	45.82	713.82	579.00	4.10
2009	6.09	182	580.82	54.36	635.18	469.49	3.50
2010	4.55	164	588.18	74.40	662.59	83.39	4.04
2011	6.50	168	616.56	69.76	686.31	404.15	4.09
2012	6.32	188	637.61	92.35	729.96	456.60	3.89
2013	6.51	191	627.65	86.25	713.90	526.30	3.75
2014	5.53	189	554.11	98.37	652.48	390.85	3.46
2015	5.25	176	571.43	100.98	672.41	248.53	3.83
2016	4.52	166	513.75	90.42	604.17	145.14	3.64
2017	4.95	188	521.88	100.98	622.85	307.26	3.31
Average	**5.53**	**178**	**559.61**	**75.78**	**635.39**	**353.42**	**3.57**

† Average rice harvest price obtained from RRVP economic analysis, 2006-2017.
‡ Average annual yield for fields enrolled in the RRVP, 2006-2017.
†† Annual average total operating and ownership expenses from fields enrolled in the RRVP, 2006-2017.

Table 17-2. State average economic information, 2006-2017.

Year	Average Ark. Rice Price†	State Average Grain Yield‡	Total Operating Expenses††	Ownership Expenses††	Total Expenses	Returns Above Total Expenses	Breakeven Price
	$/bu	Bu/A	$/A	$/A	$/A	$/A	$/bu
2006	4.11	153	461.29	80.23	541.52	88.68	3.53
2007	4.65	161	465.63	87.21	552.84	194.53	3.44
2008	7.43	148	637.73	87.03	724.76	374.88	4.90
2009	6.09	151	713.51	89.83	803.34	116.37	5.32
2010	4.55	144	635.90	79.44	715.34	-60.34	4.97
2011	6.50	150	615.54	104.03	719.57	257.96	4.78
2012	6.32	166	706.41	102.16	808.57	240.47	4.87
2013	6.51	168	714.30	104.23	818.53	274.93	4.30
2014	5.53	168	644.86	110.15	755.01	174.56	4.49
2015	5.25	163	626.27	123.31	749.58	106.35	4.60
2016	4.52	154	579.19	114.46	693.65	0.77	4.51
2017	4.95	164	547.83	115.21	663.04	150.96	4.03
Average	**5.53**	**158**	**612.37**	**99.77**	**712.15**	**160.01**	**4.53**

† Average rice harvest price obtained from RRVP economic analysis, 2006-2017.
‡ USDA, National Agricultural Statistics Service, "Rice: Acreage, Yield, Production, Price and Value," http://www.nass.usda.gov/Statistics_by_State/Arkansas/Publications/Statistical_Bulletin/Historical_Data/histrice.pdf.
†† Annual average total operating and ownership expenses calculated from University of Arkansas System Division of Agriculture rice crop production budgets for farm planning, 2006-2017.

Table 17-3. Average cost of six crop input items† in the RRVP, 2006-2017.

Year	Seed	Herbicide	Fertilizer	Fungicide	Insecticide	Irrigation
	$/A					
2006	35.34	58.23	88.61	5.29	5.66	75.95
2007	55.46	57.80	82.55	5.47	0.83	65.99
2008	65.83	83.14	203.48	10.23	6.22	108.78
2009	100.58	80.51	164.89	7.00	2.19	58.67
2010	98.12	63.06	127.91	11.49	4.81	82.65
2011	87.29	70.60	144.63	6.33	5.34	75.74
2012	77.94	70.33	167.82	10.63	1.15	65.54
2013	78.00	84.65	149.28	8.39	4.38	60.85
2014	85.52	61.10	98.48	10.19	1.15	48.82
2015	85.92	69.91	120.46	14.20	4.56	45.48
2016	100.42	67.86	86.00	8.70	4.79	39.95
2017	94.30	74.54	87.38	24.37	7.47	47.25
Average	**62.12**	**62.51**	**105.91**	**11.02**	**3.60**	**61.30**

† Average annual input cost for fields enrolled in the RRVP, 2006-2017.

economic performance of RRVP fields can be obtained in the annual RRVP summary found in the B.R. Wells Rice Research Series published by the University of Arkansas Agricultural Experiment Station and online at http://arkansas-ag-news.uark.edu/research-series.aspx. Rice production budgets and the Rice Research Series publication are available at your local county Extension office or online at http://www.uaex.edu.

Figures 17-1 through 17-4 represent a graphical comparison of average data collected from fields enrolled in the program. Yields in the RRVP, as well as the state average, have significantly increased since the program started in 1983 (Figure 17-1). There are several reasons for this yield increase: higher yielding cultivars, nitrogen adjustments, new fungicides and management practices.

Although yields have increased in both the RRVP and the state average, the RRVP cost of production (total operating expenses) has typically been less than the state average (Figure 17-2; Tables 17-1 and 17-2). This is likely due to improvements in management efficiency on the RRVP fields resulting from applying inputs based on University of Arkansas recommendations.

The average herbicide cost of RRVP fields has been cyclical. Peaks in herbicide costs were observed in 1988 and 1995, but in recent years herbicide costs have remained elevated (Figure 17-3). The costs are typically less than the state average due to timely applications, flushing when necessary and spraying only when conditions dictate the need. Herbicides like Command and Facet require moisture for activation. During most years, adequate rainfall is received during planting season for seed germination and herbicide activation. However, in some years rainfall is not received and fields must be flushed to provide the moisture for germination and herbicide activation. Also, cool temperatures during the seedling stage can result in slower rice growth, delayed flooding and, subsequently, increased herbicide costs. Flushing does add cost, but if herbicides are not activated in a timely manner, they begin to degrade and lose activity. Flushing adds cost but is cheaper than another herbicide application later.

One trend that has been observed during the program is the reduction in the amount of pounds of active ingredients applied per acre in weed control. In the RRVP, total amount of active ingredients applied as herbicides

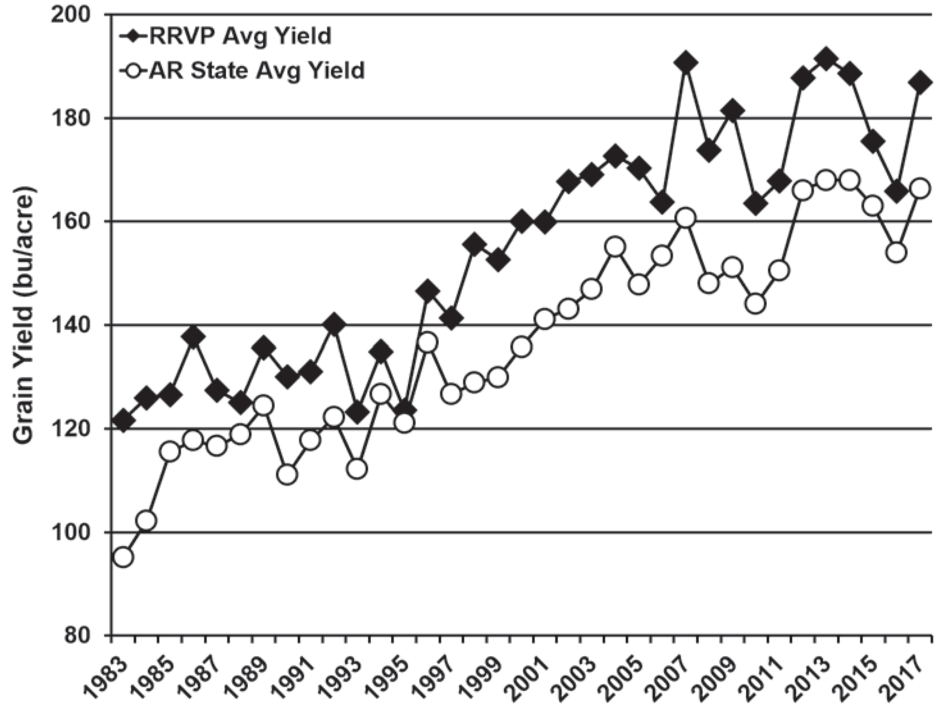


Figure 17-1. Annual average grain yields (bu/acre) for the RRVP and the Arkansas state average, 1983-2017.

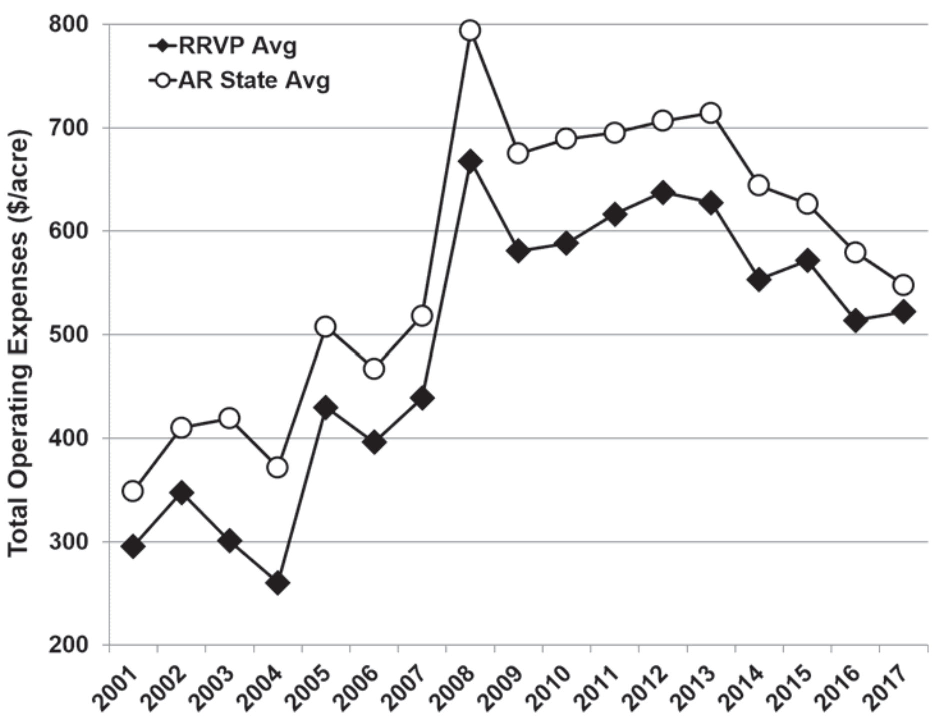


Figure 17-2. Average annual total operating expenses of rice production for RRVP and the state average, 2001-2017.

per field has reduced from more than 9 pounds ai/A to just over 3 pounds ai/A. This reduction is a result of new herbicide chemistry that has greater activity at significantly lower use rates. This is important because it relates to less environmental risk as fewer pesticides are available to be found in streams and lakes as the result of runoff from adjacent rice fields.

Fungicide applications are based on the level of diseases in each of the RRVP fields (Figure 17-3). Sheath blight is a disease that occurs every year. The climate in Arkansas is very conducive to the growth of the disease due to the hot and humid conditions. However, in the last several years new fungicides have provided an excellent tool for fighting this disease. There has been a significant increase in fungicide use in both the state and the RRVP.

Insecticide use in rice production often depends on the year (Figure 17-3). There are two major insects that have the potential to cause problems in a rice crop. They are the rice water weevil and the rice stink bug. Rice water weevils can be a significant pest in all seeding methods but are usually more of a problem in water-seeded rice. Treating for rice water weevils in water-seeded rice can be expensive and usually costs more than in drill-seeded rice. Rice stink bug numbers were high statewide in 2006, 2008, 2010 and 2011, and multiple insecticide applications were needed for adequate control.

Irrigation costs have varied greatly depending on the year (Figure 17-4). Changes in irrigation costs can be associated with

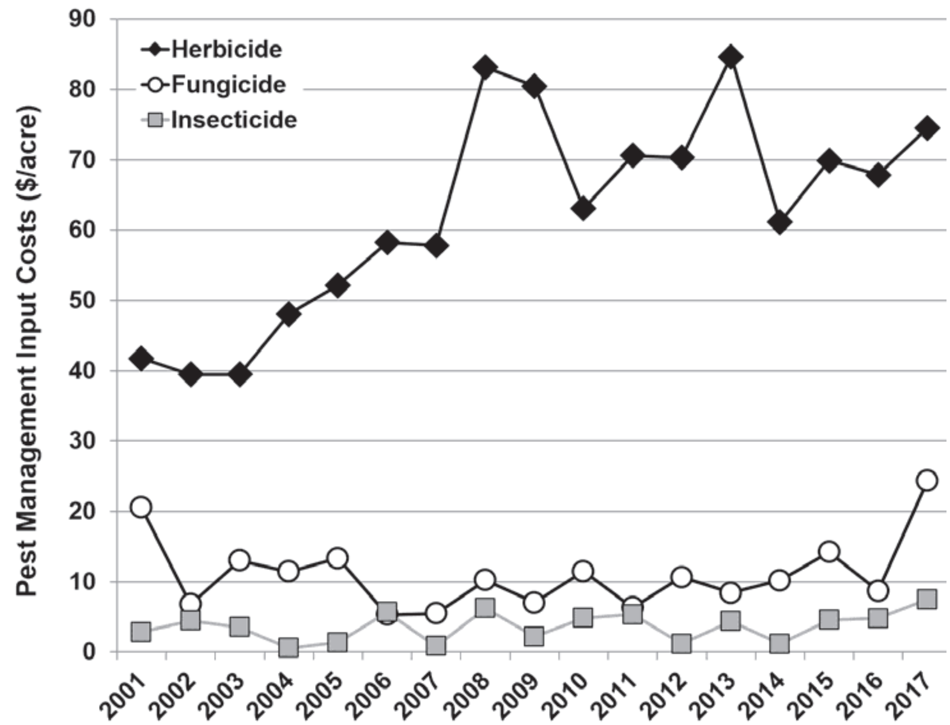


Figure 17-3. Average annual pest management costs in the RRVP, 2001-2017.

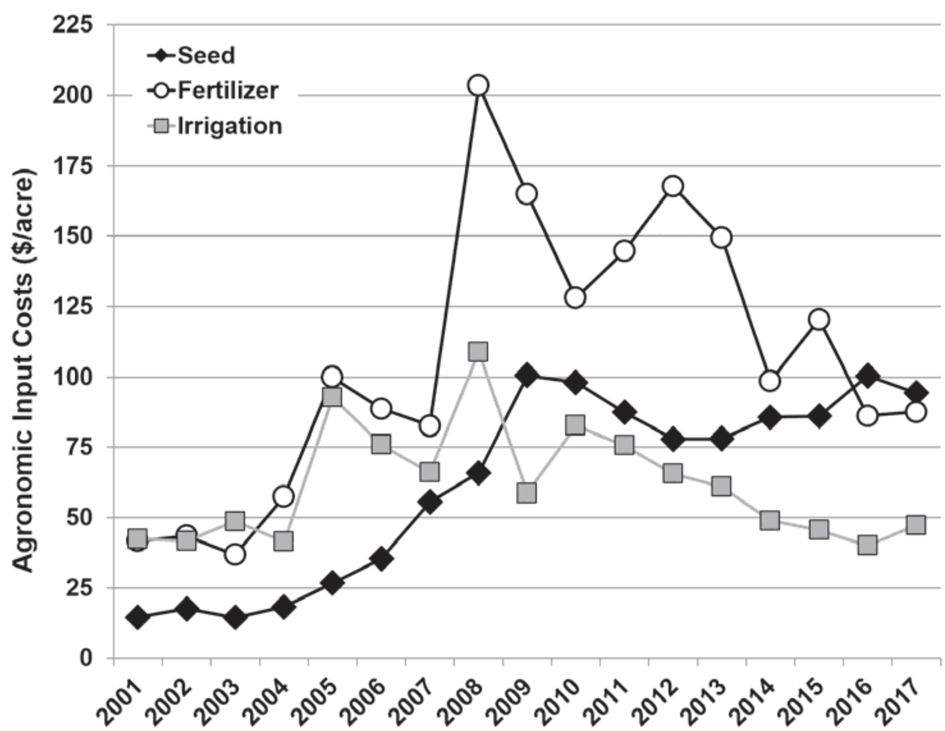


Figure 17-4. Average annual agronomic costs in the RRVP, 2001-2017.

the irrigation source utilized for the field enrolled in the RRVP. However, annual variation in fuel cost plays a significant role in irrigation costs as well.

Another goal of the program is to look for areas in rice production that require additional research. Over the last 30 years, the program has resulted in highlighting research needs in several areas.

Examples include:

- First K deficiency in rice observed
- Sulfur deficiency
- Fungicides for sheath blight/blast control
- Rice water weevil thresholds for specific cultivars
- Improvements in N management
- False smut
- Bacterial panicle blight
- Replacement for Icon

The verification program usually works with producers for two years. Cooperators and fields for the program are chosen through a joint effort involving the coordinator, county extension agents and extension district directors. Cooperators who seek to enhance their rice production skills and knowledge through personal participation in the weekly field inspections with the coordinator and county extension agent are sought for the program.

The RRVP has been successful for more than 30 years. This program has provided positive benefits to farmers, landowners, county extension agents and researchers. The RRVP continues to be the epitome of taking research to the field and educating growers on methods to increase productivity and efficiency. If you are interested in participating in the Rice Research Verification Program, contact your local county extension agent for more information.

Chapter

18

Rice Farm Safety

Jarrod Hardke and Sammy Sadaka

Farm activities often expose workers to dangerous situations. Each year, more agriculture-related deaths occur than that for any other industry. Agriculture has the greatest number of deaths per 100,000 workers at 25.4, which is twice that for the next highest industries of mining and transportation and warehousing (Table 18-1). Injury and death rates in almost every survey published are higher from April to September for agricultural work, when most farm activities occur. It is important to be aware of potential hazards in day-to-day farm operation to reduce the possibility of injury or death.

Table 18-1. **Unintentional injuries at work by industry (preliminary), United States, 2009.**

Industry Division	Hours Worked† (millions)	Deaths†		Deaths Per 100,000 Full-Time Equivalent Workers†		Medically Consulted Injuries
		2009	Change From 2008	2009	Change From 2008	
All industries	254,771	3,582	-19%	2.8	-15%	5,100,000
Agriculture‡	4,147	527	-18%	25.4	-14%	110,000
Mining‡	1,580	101	-42%	12.8	-28%	20,000
Construction	16,685	776	-17%	9.3	-1%	360,000
Manufacturing	28,049	280	-23%	2.0	-13%	600,000
Wholesale trade	7,665	165	5%	4.3	13%	130,000
Retail trade	27,469	133	-16%	1.0	-9%	580,000
Transportation and warehousing	9,527	526	-27%	11.0	-19%	250,000
Utilities	1,849	17	-54%	1.8	-55%	30,000
Information	5,874	28	-22%	1.0	-9%	60,000
Financial activities	18,075	53	-18%	0.6	-14%	140,000
Professional and business services	27,221	341	-3%	2.5	4%	240,000
Educational and health services	36,879	92	-16%	0.5	-17%	920,000
Leisure and hospitality	19,857	110	-7%	1.1	0%	390,000
Other services‡	11,927	103	-21%	1.7	-19%	170,000
Government	37,822	336	-19%	1.8	-14%	1,100,000

Deaths are preliminary data from the U.S. Bureau of Labor Statistics, Census of Fatal Occupational Injuries. All other figures are National Safety Council estimates based on data from BLS.

† Deaths include persons of all ages. Workers and death rates include persons 16 years and older. The rate is calculated as (number of fatal work injuries x 200,000,000/total hours worked). The base for 100,000 full-time equivalent worker is 200,000,000 hours. Prior to 2008, rates were based on estimated employment, not hours worked.

‡ Agriculture includes forestry, fishing and hunting. Mining includes oil and gas extraction. Other services excludes public administration.

Source: *National Safety Council Injury Facts*, 2011 Edition.

General Precautions

Work can be done safely on equipment powered by electricity with a "lock-out, tag-out" approach. Anyone working with equipment powered by electricity should carry a lock with his personal key and tag. These are readily available from local electrical suppliers. Before starting work, always disconnect the power supply and lock the switch "off." If you are interrupted or are not visible from the switchbox, this key prevents someone else from reconnecting the electricity. You can remove the lock from the switch lever after completing the work. Always use the heel of you left hand to throw lever switches and turn your face away as you move the control to minimize flash-fire burns.

A federal regulation intended for personal safety prohibits anyone or any equipment from coming within 10 feet of an overhead power line. If field equipment or other traffic cannot maintain a 10-foot gap under the power line, request that your power supplier raise the power lines.

Diesel-powered generators, electric-powered pressure washers, hand tools (drills, angle grinders, etc.) and welders should be adequately grounded. Grinders, drills and other electrical tools bouncing around in a truck tool box can develop "shorts." If the electrical service entrance at the shop is grounded with an 8-foot ground rod (National Electric Code standard), all ground wire leads, including the extra grounding plug on power cords, should be connected to reduce the risk of electrocution when the short occurs. Use electric tools on dry soil, concrete, etc., to reduce the potential of a fatal current surge passing through your body.

Someone on the farm should have current CPR training and certification. The local EMT, ambulance and fire department numbers should be posted by every permanent phone and programmed on "speed dials." Each one on the farm should be prepared to call emergency rescue should an accident occur.

Observe pesticide labels for proper use, mixing and disposal. Appropriate personal protective equipment is specified on the label. The label and material safety data sheet (MSDS) contain specific inhalation, dermal, ingestion and emergency information. These documents should be kept readily accessible so they can be referred to in case of an emergency. If a mishap occurs, use the label to help your physician and the poison center to start proper treatment.

Fire extinguishers on tractors and combines may also protect your safety and equipment investment. Dry chemical all-purpose 3A-40B:C or 4A-80B:C extinguishers are good choices for tractors and combines. Once a fire extinguisher is 10 years old, it is generally wise to replace it unless it exceeds requirements in a thorough test.

Have a Plan to Reduce Hazards

One approach is to set long-range goals to eliminate hazards while finding safer ways to complete routine tasks. Assess the potential kinds of severe accidents and how frequently a person is exposed to that hazard. Develop a simple plan that you can follow to minimize these exposures. Serious consideration should be given to the risks of road collision, tractor overturn and a person being run over or crushed by farm equipment. Consider all aspects of your farming operation to identify weaknesses and then seek remedies.

If a person must work alone, make sure another person knows where the lone worker is and that regular contact is made. If a lone operator sees a hazardous situation, getting help to resolve it is essential. Everyone should be trained to contact the manager immediately about any serious safety concern.

Field Safety

A few field dangers cause many farm-related injuries and fatalities. Since 2001, the number of agricultural work-related injuries has declined from 87,503 in 2001 to 47,332 in 2009 (Table 18-2). The primary source of injury has remained largely unchanged, with persons/plants/animals/materials, structures/surfaces and other sources responsible for the majority of work-related injuries in agriculture.

In crop production alone, 245 deaths were reported in the U.S. in 2011. Of those deaths, most were caused by transportation incidents including, but not limited to, highway and non-highway fatal injuries and fatal injuries resulting from being struck by a vehicle (Table 18-3).

Tractor overturns are the leading cause of death for farmers and farm workers. Most tractors used for rice production have a roll-over protective structure (ROPS). The risk of serious injury from an overturn is lower if the operator fastens his seat belt on a tractor equipped with ROPS! Practicing this safety habit may also reduce injury from a traffic collision. Operating a tractor, sprayer or combine too fast for conditions causes many overturns. Turning too short can cause an overturn. Misjudging the distance from an embankment can be serious, because the bank may crumble under the weight of the tractor or implement. A fact sheet available from your county Extension office, FSA1026, *Safe Tractor Operation*, http://www.uaex.edu/Other_Areas/publications/pdf/FSA-1026.pdf), has more suggestions that may be useful for training farm labor.

Table 18-2. National estimates of agricultural work-related injuries to adults (20 years and older) on U.S. farms by source of injury.

Injury Source	2001	2004	2009
Machinery	6.2%	9.5%	4.8%
Parts/materials	10.7%	5.8%	8.1%
Persons/plants/animals/ materials	27.0%	28.9%	19.3%
Structures/surfaces	24.4%	23.9%	18.5%
Tools/instruments/equipment	8.3%	7.5%	7.8%
Vehicles	7.7%	7.5%	5.4%
Other sources†	15.7%	16.9%	36.1%
Total‡	87,503	80,329	47,332

†Includes chemicals and chemical products, containers, furniture/fixtures and other/unknown sources.

‡Estimates may not sum to total due to rounding.

Source: *Occupational Injury Surveillance of Production Agriculture Survey*, 2001, 2004 and 2009.

Table 18-3. Fatal occupational injuries by event or exposure, 2011.

Event or Exposure	Percent of Fatalities
Violence and other injuries by persons or animals†	4.9%
Transportation incidents‡	55.5%
Fires and explosions	2.9%
Falls, slips, trips	7.3%
Exposure to harmful substances or environments	9.0%
Contact with objects and equipment	19.6%

†Includes violence by persons, self-inflicted injury and attacks by animals.

‡Includes highway, non-highway, air, water, rail fatal occupational injuries and fatal occupational injuries resulting from being struck by a vehicle.

Source: *Bureau of Labor Statistics 2001 Census of Fatal Occupational Injuries*.

Whether calibrating a planter or sprayer or moving a combine, don't move equipment until you see that everyone is out of danger. Starting a tractor in gear from the starter terminal (jump-starting) is a common reason farm workers have been run over. Transmission interlocks prevent tractors from starting in gear, unless the safety is bypassed. A victim does not have enough time to jump away from a tractor left in gear before the engine builds hydraulic pressure and the tractor rolls over him.

Whenever noise prevents you from hearing someone, stop the engine and what you are doing and move to where you can talk to clear up any confusion. Hand signals are easily misunderstood, unless both individuals understand the meaning of a hand movement in advance. It takes good communication and cooperation for two people to safely hitch heavy toolbars or towed equipment. Make sure signals are not confusing before moving the tractor to align the connection.

Using a proper hitch support may prevent a dangerous hitching incident. If the hitch or lift pins do not align, movement may knock the support from under the equipment; the toolbar or hitch may spring out of control or drop and crush someone's foot or leg. Two severe accidents in 2002 may be instructive. One employee was killed trying to remove a pin when the hitch broke free and struck him in the head. Another victim removed a latch pin and was crushed by a folding cultivator because the hydraulic cylinder did not support the weight. If supports are not sturdy, stable and at the proper height when disconnecting an implement, difficulty is likely when hitching the next time. Set the safety locks on the lift cylinders before working under a combine header. Never work under hydraulic lifts, mowers, or toolbars without sturdy supports.

Combine entanglements are rare the first time the machine is choked and plugged. It's the fourth or fifth time, or later, when the operator is tired or irritated, in a hurry and judgment lapses. Vibration and excessive noise dull an alert person's senses to hazards. Since fatigue slows reaction time, rest breaks help refresh the body. Falls from combines, grain bins, etc., may be prevented with proper work platforms or sturdy ladders. Keep work areas neat and free of hose or electrical cord loops, etc., which could pose trip hazards.

Professionals mount large implement tires with a protective cage. Mishaps while inflating tires can maim or kill. If appropriate equipment to handle these tires safely is not available, it is best to call a professional tire service company.

Irrigation risers, discharge pipes and "washout" holes where water discharges may become hazards if they are not clearly visible. If field equipment runs over a riser or washout, it can cause temporary loss of control in addition to damaging the equipment and/or the riser. Placing some type of readily visible marker around each riser and controlling weeds so the marker is readily visible should help to alert drivers. Anchor and guy wires from power poles located near or in fields should also be permanently marked. Putting some type of solid protection around guy wires for power poles is a good idea to help avoid clipping or dislodging them with field equipment. Fill washout holes and use some erosion control structure or method to prevent large washouts under discharge pipes.

Agricultural aviators have little reaction time to dodge hazards as they apply fertilizer and pesticides. Always warn the pilot of any risks that you are aware of to help him be better prepared. If a field has aerial hazards, consider whether ground equipment may be more appropriate.

Grain Handling Safety

Flowing grain and entanglement are the top causes of fatalities in grain handling facilities. Entanglement from moving fans, blades, augers, power take-offs (PTOs), belts, gears and pulleys can severely injure, disfigure, amputate or cause death to workers. Flowing grain, on the other hand, is the number one cause of fatalities for grain handlers. Large or unstable quantities of grain can flow like liquids. Unlike water, which allows a person to swim, it is difficult or impossible for a grain handler to move if he/she is caught in grain. If a grain handler is caught in a grain flow, he/she can be buried in a few seconds, which may result in suffocation in grain.

The number of agricultural confined-space incidents in the U.S. between 1964 and 2012 totaled 1,500 cases, as reported by a Purdue University database (Table 18-4). The majority of these cases are related to entrapment or engulfment in free-flowing grain. Other cases are related to machinery entanglement inside grain storage facilities or from asphyxiation due to toxic atmosphere in partially closed storage structures.

Table 18-4. **The number of nonfatal and fatal incidents related to grain entrapment in the U.S. (adapted from Issa and Field, 2013).**

Year	2007	2008	2009	2010	2011	2012
Nonfatal	15	17	22	26	19	11
Fatal	16	17	19	31	11	8
Total	31	34	41	57	30	19
Fatal/Total	51.6%	50.0%	46.3%	54.4%	36.7%	42.1%

Source: Issa and Field, 2013. *Summary of Grain Entrapments in the United States*. http://extension.entm.purdue.edu/grainlab/content/pdf/2012GrainEntrapments.pdf.

Grain Bin Entrapment and Engulfment

The term entrapment implies an incident when a grain bin worker becomes buried in the grain beyond the point of self-extraction. On the other hand, the term engulfment implies an incident when a grain bin worker is completely buried or submerged beneath the surface of the grain, as shown in Figure 18-1. In many cases, grain entrapment leads to engulfment which, in turn, is always fatal.

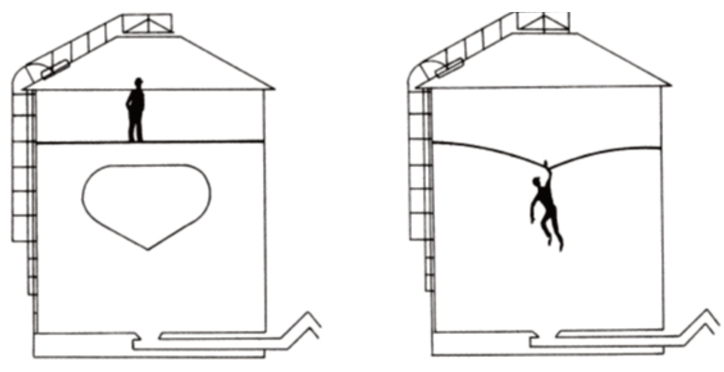


Figure 18-1. **Grain bin engulfment (right).**

Causes of Grain Bin Entrapment

According to the Occupational Safety and Health Administration (OSHA), most entrapments suffered by grain handlers who have entered bins or silos resulted when:

1. Grain handlers were without personal protective equipment.
2. Grain handlers did not follow proper safety procedures.

3. Grain handlers entered bins or silos while grain was flowing and equipment was running and he/she was sucked under the grain.
4. Grain handlers fell through bridged grain into an air pocket which was formed beneath spoiled grain (Figure 18-2).
5. Grain handlers tried to break a vertical grain wall (Figure 18-3).

Figure 18-2. Bridged grain.

Figure 18-3. Vertical grain wall.

Duration of Grain Bin Engulfment

The following example will provide an idea of how fast engulfment occurs. Normally, a bin-unloading auger moves grain from farm storage at 2,000 to 10,000 bushels per hour. Assuming the grain moves at a rate of 4,086 bushels per hour, this is approximately 85 cubic feet of grain moved per minute. The volume that a 6-foot-tall person takes up is roughly 7.5 cubic feet. At 85 cubic feet of grain movement per minute and from the time the auger starts, the entrapped person has 2 to 3 seconds to react. This person will be trapped in about 15 seconds. The entire body of a 6-foot-tall person can be completely engulfed within grain in about 30 seconds. Without immediate rescue, this person will suffocate.

Tips to Help Avoid the Danger of Grain Entrapment and Engulfment

Grain bin entrapment and engulfment are avoidable events. The best prevention for grain engulfment is to avoid entering the grain bin. However, it should be mentioned that flowing grain incidents could occur from loading and unloading trucks and bins, collapsing surface crusts and collapsing steep or vertical grain piles. Accordingly, the following tips may help avoid these deadly incidents.

1. Grain handlers should avoid entering a bin of flowing grain. If a grain-probe or shovel is dropped in grain bin, the flow of grain should stop first before taking any action to retrieve the lost item.
2. Grain handlers should know or be wary about a grain bin's history before entering. He/she needs to get help if the grain surface appears moldy or caked. It is advisable that grain handlers strike the grain surface hard with a pole or long-handled tool before entry to avoid falling into a crusted layer.
3. Grain handlers should lock out/tag out related power equipment before entering any bin. It may also be wise for the grain handler to post a sign on the control box.
4. Grain handlers should padlock the control gate to keep it closed if a bin is unloaded by gravity flow.
5. Grain handlers entering a grain bin should have a body harness tethered to a lifeline that is manned by at least two others outside the bin; one should be able to see the grain handler inside the bin while the second can provide aid if necessary.
6. Grain handlers should be able to use prearranged arm and hand signals due to difficulty hearing when grain handling or drying equipment is operating nearby.
7. Grain handlers trying to rescue one victim should not endanger another person.
8. Grain handlers should prepare appropriate breathing apparatus if the victim has been unable to get sufficient oxygen or has been breathing air containing grain toxins.
9. Grain handlers should take into account all preventative safety measures which include proper ladders, scaffolds, etc.

Grain Bin Entrapment Rescue Technique

Remember, entrapped persons need immediate help. It is much easier to help and successfully rescue the trapped person if you have an accident response plan. The trapped person should contact the helper waiting outside the bin immediately. It should be mentioned that pulling a trapped person from grain could be very difficult due to the friction forces transferred from the grain to the trapped person's body. Therefore, it is not advisable to winch a person from grain if the person is buried deeper than knee deep. This may cause joint dislocation, paralysis and other severe injuries. The grain must be removed from around the person to get him/her out. It can be done by cutting balanced holes in the sides of the grain bin or by creating a cofferdam around the person and bailing out grain with a vacuum or bucket. Grain cofferdams can be constructed by driving sheets of plywood around the person. They can also be constructed out of plastic barrels. Currently, there are several commercially available grain rescue tubes. They have linking pieces that are connected and driven into the grain to create a cofferdam. Commercial rescue tubes typically have steps on the inside to assist the victim in climbing out of the grain.

Traffic and Road Transport Safety

The National Highway Traffic Safety Association recently reported that approximately 40 percent more fatal crashes and fatalities occur in rural areas compared to urban areas. Experience over the last four years in crop areas of Arkansas seems to reinforce national statistics. Changes like wider road shoulders, adding warning signs for curves with poor visibility, updating narrow bridges and, possibly, adding crossbars at railroad crossings should reduce rural traffic accidents. In some situations, it may be possible to convince town, county, state or railroad officials to clear right-of-ways to allow better traffic visibility.

Modern toolbars, combines and wide equipment typically require almost two normal traffic lanes. Motorists are often poor judges of the slow speed, width or weight of farm machinery traveling on roadways. Using an escort with flashing lights is probably the best way to alert motorists. Being diligent to keep SMV signs, reflectors and taillights bright, cleaning them before entering a road, will improve their visibility during night and day.

Lock both brakes together and start onto roadways slowly. Go slowly enough to manage the momentum of the tractor with a full grain cart, grain drill or toolbar, particularly those that raise overhead. Dump all of the rice from the combine into a grain cart or truck prior to road travel to lower the center of gravity and increase the ability to maintain control in a sudden emergency. Always check traffic from both directions before making turns, especially left turns, to prevent collision, extensive damage and injury.

Railroad crossings are increasingly dangerous for growers on farm equipment. Some cabs may "tune out" the diesel train noise. In order to hear more effectively, reduce the speed of the cab fan and turn off the radio as you approach a crossing. If you gear down well in advance, you can control the load, either to stop or to proceed when the track is clear. In some cases, either historical evidence and/or community effort may help to get the railroad to add crossbars.

Irrigation Safety

A qualified electrician should routinely check electrical circuits on irrigation pumps and center-pivot systems. Items to review are proper grounding and adequate circuit protection, including immediate replacement of circuit boxes damaged by electrical storms or circuit overheating. If a box has overheated or shorted, switching the disconnect lever may cause arcing and severe flash burns that may take months for merely partial recuperation. Always use the heel of your left hand to throw switch levers and turn your face away to minimize hazard exposure as the control is moved.

Be cautious when working around electrical circuits, especially when opening electrical control boxes and around any circuits that are "hot." Wasps commonly nest in and around electrical control boxes and may also appear from electric motor shrouds, gear head covers, power unit platforms, irrigation well sheds and irrigation pipe openings. In order to prevent an injury, it may be wise to keep wasp and hornet spray insecticide handy when working on irrigation wells. Stings are not only painful; they can be fatal for one who is severely allergic to insect stings. Further injury can also occur if a wasp startles you and causes you to jump away. A sudden reaction that puts you in contact with an unguarded drive gear or energized electric circuit may cause serious injury.

Entanglements may occur with irrigation well power shafts if safety shields are not in place. In general, power-take-off (PTO) hazards are respected, but more emphasis needs to be placed on shielding unguarded power shafts on irrigation wells. Power shaft covers can be obtained from suppliers, such as Menard Manufacturing in DeWitt, Arkansas (1-888-746-3130) to protect those doing maintenance around diesel, propane or electric power units. Power shafts for relifts or well pumps should be shielded; any concentric sleeves that do not spin freely should be repaired or replaced.

If a power unit is not securely mounted and anchored, vibration may misalign the drive or break it loose from the supports. A loose power unit may cause a dangerous flailing power shaft or other hazards due to broken electrical wires, fuel lines or battery cables. Power units and battery mounts should be securely anchored to a substantial support platform and routinely checked for stability. A secure latch to keep the clutch of the power unit in neutral is a good safety device. This can help prevent accidentally bumping and engaging he clutch when working close to the power unit.

Typically, weather is very hot when irrigation is needed, and physical stresses may bring on heat stress. Anyone working in these conditions should drink plenty of fluids, such as water and nutrient-replenishing drinks. Breaks and rest periods should be taken as needed to avoid heat stress, fatigue and exhaustion. Fatigue and exhaustion, of themselves, are health hazards, but they may also contribute to poor judgment, causing other accidents and injuries.

Reservoirs and open irrigation distribution ditches may present concerns. Normally, a clear warning on a sign about the water hazard, unusual currents around culverts, etc., and potential bank washouts will caution outdoorsmen or others who may enter. Evaluate a location with respect to residences or public access to determine whether it may attract youngsters. Gates and fencing may be used around accessible areas to prevent ATV riders or children from getting into danger. Posting no trespassing signs or a drowning warning is primarily useful only for adults.

OSHA

Employee safety is regulated by the Occupational Safety and Health Administration. Regulations change periodically, so for the most current information, please refer to the following website: https://www.osha.gov/index.html.

Summary

These suggestions are a start to help manage hazards and find ways to avoid them. These hazards are only highlights. Review your techniques and farm work sites in order to reduce potential hazards.

A grower's leadership is the key to influencing employees and others on the farm. Employees must know that working safely is expected, for their welfare as well as that of their employer. During the noncrop season, it is wise to make a careful hazard audit. Review the previous season's activities and field records to bring to mind hazards or incidents, especially considering situations when someone narrowly avoided serious injury. Making changes may save someone's life the next season.

In most situations, equipment is not the underlying cause of an accident. A single thoughtless reaction can make you a victim. Never get in a hurry. Plan ahead to ensure there is enough time to do the job properly and safely.

Contacts That May Prove Helpful

Emergency Rescue	911 or__________
Poisoning	1-800-222-1222
Family Physician	
Local Electric Power Supplier	
County Sheriff	
Local Implement Dealer (assist with extrication)	
Local Implement Dealer (assist with extrication)	
Arkansas State Highway and Transportation Department (Police: Oversize and over-weight permits, etc.)	501-569-2381
Commercial Driver's License (CDL) Info	501-682-1400
State Fire Marshal, Arkansas State Police (Fuel storage questions)	501-618-8624
Arkansas State Plant Board	501-225-1598
Arkansas Department of Environmental Quality	501-372-0688
LPG (Liquified Petroleum Gas) Board	501-324-9228

Chapter

19

Glossary of Rice Industry Terms

Aging – physiological changes that rice undergoes predominately during the initial three postharvest months.

Amylopectin – one of two major starch molecules characterized by glucose units arranged in a linear, unbranched chain. Higher concentrations contribute to drier, less sticky cooked rice.

Anthesis – the series of events between the opening and closing of the rice flower (spikelet). Also referred to as flowering.

Aromatic (scented) Rice – rice that contains high concentrations of volatile constituents yielding an aroma similar to roasted popcorn or nuts.

Auricles – clasping appendages arising at the junction of the leaf blade and the leaf sheath.

Basmati Rice – a type of aromatic rice that tends to cook into long, slender grains that are dry, separate and fluffy.

Barrel – a unit of measure of rough rice used in some areas of the U.S.; equivalent to 162 pounds of rough rice (3.6 bushels).

Booting – the stage prior to heading characterized by the swelling of the leaf sheath as the panicle grows in size and the internodes elongate, pushing it up through the leaf sheath. During this stage, meiosis occurs and the pollen is formed. It is one of the stages most vulnerable to environmental stresses.

Bran – the outer layers or coverings of brown rice; composed of the pericarp, seed coat and aleurone layer. (Note: industrial bran normally is a mixture of bran and embryo).

Breeder Seed – Seed reserved for licensed plant breeders for the production of foundation, registered or certified seed; marked with a white tag.

Brewers Rice – small pieces of broken rice kernels.

Brown (cargo) Rice – the rice kernel with the protective hull removed.

Bushel – a volumetric measure of rough rice approximately equivalent to 45 pounds of rough rice.

Caryopsis – the mature fruit of grasses in which the seed coat firmly adheres to the pericarp.

Certified Seed – produced by planted either registered or foundation seed and guaranteed for purity by the State Plant Board; marked with a blue tag.

Chalky Rice – rice that has a brittle texture due to loose packing of starch granules in the grain; resulting in weaker grain that is more susceptible to breaking.

Coleoptile – the topmost part of the embryo axis that serves as a protective sheath for young leaves and the growing point during seedling emergence.

Converted Rice – *see parboiled rice*. The term "converted rice" is a trademark.

Crown – the compacted section at the base of the stem containing the nodes for new tillers and buds for new roots.

Culm – a commonly used name for the stem of a grass-type plant, such as rice, consisting of nodes and hollow internodes.

Cultivar – an inclusive term that represents lines, hybrids, selections, or varieties of crops. (See also **Hybrid, Variety**)

Embryo (germ) – the reproductive portion of the rice grain located on the ventral side.

Endosperm – the white central portion of the rice grain, composed primarily of starch.

Enrichment – the addition of specific nutrients to partially compensate for those lost during the milling process. Regulations in the U.S. specifically stipulate that enrichment for rice must contain thiamine, niacin, and iron and may contain riboflavin.

Flag Leaf – the last leaf to develop on a tiller that emerges during the boot stage and fully extends in the full boot stage. A major source for carbohydrates and nutrients for the developing panicle.

Flowering – (see **Anthesis**)

Fortification, Glazing – (see **Enrichment**)

Foundation Seed – produced by planting breeder seed. Is reserved for licensed plant breeders but may be produced under the direct supervision of a licensed plant breeder to maintain genetic purity and identity of the cultivar. Used to produce registered or certified seed; marked with a white tag.

Gelatinization Temperature – the temperature at which irreversible swelling of the starch grains leads to formation of a gel (induced by hot water).

Genetically Modified Organism (GMO) – a plant or animal that has a gene inserted from another organism resulting in the expression of a desirable trait.

Green Ring – (see **Panicle Initiation**)

Hard Dough Stage – part of the process of grain ripening characterized by a firm whole kernel but moisture content greater than 20 percent.

Heading – growth stage when the panicle exserts from the boot, often synonymous with anthesis or flowering of the spikelets. Heading date is defined as the time when 50% of the panicles have at least partially exserted from the boot. It takes about 10 to 14 days for a field to complete heading.

Head Rice – after milling, unbroken kernels of rice and broken kernels which are at least three-fourths the length of an unbroken kernel. Usually expressed as a percentage of rough rice (referred to as head rice yield [HRY]).

Heat Damaged Grains – kernels of rice which have a reddish-brown to orange color and are substantially darker than the majority of the grain. This defect may occur in either white or parboiled rice.

Hull – the outer covering structures (palea and lemma) that enclose the rice kernel.

Husk – (see **Hull**)

Hundredweight (cwt) – a mass measurement of rice yield equal to 100 pounds of rough rice (2.22 bushels).

Hybrid – the first-generation progeny of a cross between two plants of the same species but have different genetic backgrounds (e.g., different varieties or lines).

Imbibition – initial process of seed germination characterized by water absorption into the seed.

Indica Rice – subspecies of rice that typically is long-grain, has high amylose contents, profuse tillering, high pubescence (hairy leaves); typically grown in tropical climates; tends to cook dry, loose and fluffy.

Instant Rice – a type of precooked rice that is easily rehydrated at temperatures below boiling. Typically it is fully hydrated in less than 5 minutes when added to boiling water.

Internode Elongation – the period when the internodes elongate and the plant grows in height. It begins about the time of panicle initiation (PI) and continues until the plant reaches its full height. Internode elongation is often called “jointing”.

Japonica Rice, Temperate – subspecies of rice characterized as medium- and short-grain rice with low amylose content (10-20%) which causes it to cook wet and sticky; typical of most U.S. medium- and short-grain varieties.

Japonica Rice, Tropical – subspecies of rice characterized as long-grain rice with intermediate amylose contents (20 to 25 percent), low tillering, smooth leaves (not hairy); typical of most U.S. long-grain varieties.

Jasmine Rice – an aromatic long-grain rice that cooks moist and often clings together.

Lemma – the part of the rice hull which covers two-thirds of the surface area of brown rice.

Length, Kernel – the distance between the most distant tips of the kernel.

Ligule – a membranous fringe on the inner side of the leaf at the top of the leaf sheath of rice and other grass plants.

Maximum Tillering – the point at which the maximum tiller number is reached and the main culm is difficult to distinguish from the tillers.

Meiosis – the process of cell production which reduces the chromosome number in the new cells by one-half the number in the parent cells (reduction division). Sex cells are formed by meiosis.

Mesocotyl – the internode between the scutellar node and the coleoptile.

Milk Stage – the first step in the grain-ripening process characterized by developing starch grains in the kernel that are soft and the interior of the kernel is filled with white liquid resembling milk.

Mill, Rice – a machine for removing the bran from the endosperm. Mills are of two general types: *polishers* that rub the bran off (friction-type mill or pearlier) and *whiteners* that grind or strip the bran away.

Milled Rice – whole or broken kernels of raw or parboiled rice from which the hulls, bran, and germ have been removed. Usually expressed as a percentage of rough rice.

Milling, Degree of – the extent to which the bran layers and germ are removed from the rice endosperm.

Milling Yield – after milling, the quantity of total milled rice produced in the milling of rough rice to a well-milled degree (includes all kernels whole and broken), usually expressed as a percent of rough rice (total milling yield [TMY]), but when specified may be expressed a percent of brown rice.

Palea – the part of the rice hull which covers approximately one-third of the surface area of brown rice. Its edges fit inside those of the lemma forming a tight closure.

Panicle Differentiation – when the young panicle has grown about 1 to 2 mm long and can be seen by the naked eye. Generally occurs about 5 to 7 days after panicle initiation when the internode is ½ to ¾ inch in length.

Panicle Initiation (PI) or Panicle Primordia Initiation – corresponds to the time when the fourth leaf from the top begins to elongate, approximately 30 days before heading. The panicle is not visible to the naked eye. Often called *green ring* or *beginning internode elongation*.

Parboiled Rice – rice that has undergone a parboiling process.

Parboiling (converting) – a hydrothermal process in which the crystalline form of starch is changed into an amorphous one, typically accomplished by soaking, steaming, and drying rough rice; typically increases the percentage of head rice and the vitamin content in the milled rice.

Pecky Rice – discoloration of rice grain due to rice stink bug feeding, environment, diseases, and other factors; generally results in easily broken kernels.

Physiological Maturity – the end of the grain filling period, at which time growth increases are in balance with metabolic losses.

Polishing – the removal of traces of bran that remain after milling; resulting in a smooth surface that has a glossy appearance (see **Milled Rice**).

Quality, Rice – the composite of characteristics that differentiate individual units of rice and have significance in determining the degree of acceptability by the consumer. Rice quality components include milling quality; cooking, eating, and processing quality; nutritional value; and specific standards for cleanliness and purity.

Quick Cooking Rice – rice that has been pretreated so as to substantially reduce the cook time, especially rice that has been cooked in water, steam, or both, then dried in such a manner as to retain an open, porous structure without clumping.

Red Rice – rice of the same genus and species as white rice but characterized by a red seed coat. The hull may be black or straw-colored. Noxious weed because of discoloration of white rice.

Registered Seed – used to produce certified see. Produced by planting breeder or foundation seed; marked with a purple tag.

Rough (paddy) Rice – whole or broken unhulled kernels of rice.

Shell – (see **Hull**)

Stabilized Rice Bran – rice bran that has been treated to essentially inactivate or inhibit enzymes that hydrolyze lipids to release free fatty acids.

Soft Dough Stage – part of the grain-ripening process characterized by the initial starch formation in the grain. The interior of the kernel is firm, but still soft.

Tillering – production of tillers which are shoots that develop from the leaf axils at each un-elongated node of the main shoot and from other tillers. Tillers are produced in a synchronous manner, the *n*th leaf on the main culm (or tiller which is producing tillers) and the first leaf of the tiller on the (*n*B3)th leaf emerges simultaneously.

Variety – a genetically pure line of a crop species that exhibits certain traits; seed will produce plants that exhibit the same traits as the original plant. An experimental line becomes a variety when it is officially named and released for commercial production.

Vegetative Lag Phase – the period from the end of active tillering (maximum tiller number) to the beginning of the reproductive stage which occurs upon initiation of the panicle primordial.

Waxy Rice – rice whose starch contains less than 2 percent amylose.

Width, Kernel – the distance across the kernel at the widest point.

Y-Leaf – "young leaf"; the youngest, fully developed leaf on the plant.

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