RBB Consulting, LLC

SOUTHLAND ENVIRONMENTAL

November 3, 2025

Mr. Turner Brumby
Veron, Bice, LLC
721 Kirby Street
Lake Charles, Louisiana 70601

RE Comments to Site Investigation Report and Proposed Remediation Plan
Danny Paul Gastal and Ignatius Hoffpauir v. Petrodome Operating, LLC, et al.
Morse Oil and Gas Field
Acadia Parish, Louisiana

Dear Mr. Brumby:

Per our conversation, RBB Consulting, LLC (RBBC) and Southland Environmental, LLC (SLE) have prepared a review of the Site Investigation Report and Proposed Remediation Plan (October 3, 2025). The report/plan was prepared for Petrodome Operating, LLC and Ichor Energy (LA) LLC (Petrodome Defendants), and submitted pursuant to a limited admission they made in the lawsuit captioned, *Danny Paul Gastal and Ignatius Hoffpauir v. Petrodome Operating, LLC*, et al., Morse Oil and Gas Field, Acadia Parish, Louisiana. That report is herein referred to as the "Petrodome Limited Admission Plan" or the "Plan".

Our review is intended to evaluate the Plan for compliance with Statewide Order 29-B (29-B) and Louisiana Department of Conservation and Energy (C&E), formerly the Louisiana Department of Natural Resources (LDNR), requirements for limited admission plans. Comments are discussed below.

We have attached current copies of our curriculum vitae as Attachment 1.

<u>Depth Limit of 29-B Soil Standards</u>

The Petrodome Limited Admission Plan finds the maximum effective root zone is six to ten inches below ground surface for plants growing on the Gastal tract and concludes the 29-B standards are only applicable to soils within the so-called effective root zone. Thus, the Plan places a depth limit of approximately one foot for compliance with 29-B soil standards. In other words, the Plan does not address any regulatory exceedances of the 29-B soil standards below a depth of approximately one foot.

The 29-B Regulations define Exploration and Production Waste (E&P Waste) as *"drilling wastes, salt water, and other wastes associated with the exploration, development, or production of crude oil or natural gas wells ……"* (LAC 43:XIX.501). The definition does not include minimum concentrations, nor does it provide depth limitations for regulatory compliance.

On October 3, 2013, C&E emphasized the lack of a depth limitation in the 29-B Regulations when it issued its "Written Reasons In Support of Most Feasible Plan as Required by LA. R.S 30:29" as a result of the limited admission hearing in *Agri-South, LLC et al. v. Exxon Mobil Corporation, et al.*, (Docket No. 24,132, Seventh Judicial District Court, Parish of Catahoula) (Attachment 2). In its written reasons, C&E explains *"There is no depth limitation included in the 29-B salt standards. Salt parameter exceedances below three feet must meet the 29-B standards, unless there is an exception for good cause granted pursuant to LAC 43:XIX.319 which addresses LAC 43:XIX.313 soil conditions for salt parameters below three feet."*

The Petrodome Limited Admission Plan only addresses 29-B exceedances to approximately one-foot and ignores any such exceedances in the soils on the Gastal tract below that depth. To date, no exceptions have been granted that would allow soil contamination in excess of the 29-B Regulations to remain on the Gastal tract. It is our understanding that the landowner, Danny Gastal, is not consenting to any exceptions. Thus, the Petrodome Limited Admission Plan is not in compliance with LAC 43:XIX.611.F.1.

<u>Underground Sources of Drinking Water</u>

Current site investigation data are insufficient to determine the impact of produced water contamination on groundwater quality within the permeable zones of either the Chicot Aquifer Surficial Confining Unit or the Chicot Aquifer Upper Sand Unit. Investigation data to date indicates that exceedances of the 29-B Regulations are widespread and contaminant migration pathways are present. No site specific subsurface geologic/hydrogeologic features that would impede vertical contaminant migration have been identified. A review of the current site-specific data reveal the following:

- Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR), and Exchangeable Sodium Percentage (ESP) exceed 29-B Regulations at depths ranging from 1-60 ft-bgs.

- EC readings greater than 10 mmhos/cm are present at depths ranging from 2-60 ft-bgs.

- The extents of SAR and ESP regulatory exceedances associated with the Petrodome spill event have not been defined because Petrodome Defendant's SAR and ESP analysis were limited to samples collected from 0-4 ft-bgs.
- The presence of EC concentrations in excess of the 29-B Regulations standard at a depth of at least 60 ft-bgs confirms the vertical permeability of soil/sediments and the hydraulic interconnectivity of subsurface soil/sediment beneath the Gastal tract.
- Installation and monitoring of two groundwater monitor wells, MW-01 screened interval 6-16 ft-bgs and MW-01D screened interval 22-32 ft-bgs, indicate saturation of the monitored intervals is transient as infiltrating surface water migrates through the surface soil/sediments of the Chicot Aquifer Surficial Confining Unit. The absence of a near surface saturated groundwater zone confirms this infiltration process is not impeded by continuous low permeability soil/sediments and emphasizes the permeability and hydraulic interconnectivity of subsurface soil/sediment.
- Soil in the area of boring B-7 have produced water impacts at greater depth than produced water impact observed in the source area (Boring B-5). This confirms lateral and vertical migration toward adjacent properties and the Chicot Aquifer is taking place. In addition, the produced water impacts documented in boring B-7 (EC= 12.40 at 58–60 ft-bgs) have not been laterally delineated to the south.
- Stratigraphic data from soil borings and cone penetrometer tests have not identified a continuous low permeability interval that might impede the vertical migration of produced water to the underlying saturated sands within the Chicot Aquifer Surficial Confining Unit or the Chicot Aquifer Upper Sand Unit.

To date, no groundwater samples have been collected/analyzed to assess the impact of produced water from the Petrodome spill event on underlying aquifers within the Chicot Aquifer Confining Unit or the Chicot Aquifer Upper Sand Unit.

The Petrodome Limited Admission Plan utilizes the Louisiana Department of Environmental Quality (LDEQ) Risk Evaluation/Corrective Action Program (RECAP) Synthetic Precipitation Leaching Procedure (SPLP) analyses to exclude the necessity for investigating groundwater beneath the Gastal tract and determining, firsthand, the impact, if any, of the Petrodome spill event on groundwater aquifers and the USDW underlying the Gastal tract.

The February 25, 2011 LDNR/LDEQ Memorandum of Understanding ("MOU"), Item No. 2, indicates application of RECAP for evaluation or remediation of groundwater at E&P sites is considered an "exception" to Statewide Order 29-B. C&E confirmed this in its written reasons in support of its most feasible plan in the *Agri-South* case mentioned above. (Attachment 2, p. 15).

To date, no exceptions have been granted that would allow the use of RECAP on the Gastal tract. In addition, the extent of the produced water impacts has not been fully delineated. Thus, the Petrodome Limited Admission Plan is not in compliance with LAC 43:XIX.611.F.1 and LAC 43:XIX.611.B *("Each plan shall fully delineate the vertical and horizontal extent of the environmental damage.")*.

It is also important to note, the Introduction of the RECAP document states: *"It does not authorize any injury to private or public property (refer to Section 2.20) or any invasion of personal rights, nor any infringement of federal, state, or local laws or regulations, and does not authorize the migration of COC offsite to adjacent property."*

Actual and Potential Uses of the Gastal Tract

Currently, the Gastal tract is used for aquaculture (crawfish) and agriculture (rice) production although the impacted fields have remained fallow since the Petrodome spill event. The Plan does not consider rice tolerance to salt but instead considers the 29-B standard sufficient for rice production. That is not the case, as rice is among the crops most sensitive to salt with reduction in crop yield occurring at EC levels as low as 2 mmhos/cm (Louisiana Rice Production Handbook, Attachment 3). In addition, the Plan fails to evaluate the effect of produced water impacted soil on pore water salinity at a depth of 0-4 ft-bgs, the common burrow depth for crawfish (Louisiana Crawfish Production Manual, Attachment 4").

Although the current use of the Gastal tract is for agriculture/aquacultue, the Plan fails to consider alternative land use scenarios for the Gastal tract. Some alternative use scenarios include:

- Rotation of agricultural activities from crawfish and rice to alternative crops with deeper effective root zones, exposing the alternative crop to E&P waste and increasing the potential for reduced crop yield or failure.
- Transition from agricultural land to recreational pond use or commercial dirt pit. Excavation of large quantitities of soil below the approximately 1-ft bgs remediation zone would likely be associated with either activity.
- Residential, commercial or industrial development would likely include clearing/grubbing and excavation for road construction, parking lot construction, house pad construction, utility and sewer installation, excavation of storm water retention and/or landscape ponds as well as the installation of foundation pilings. All of these activities would likely remove or disturb the soil in the "effective root zone" and expose site workers, the public and surface water resources to E&P waste.

The Gastal property abuts residential and commercial portions of the Village of Morse. If extended just 200 feet to the north, Pugh Avenue and Foreman Avenue would reach impacted areas of the Gastal tract. Residential parcels directly adjoin the Gastal tract and existing residences are located within 200 feet of surface scars. Development of the impacted areas on the Gastal tract for residential use should be considered.

A portion of the Gastal tract was commercially developed in 2024. Specifically, a Dollar General was constructed and is currently an active commercial site. It is not unreasonable to consider the potential for further commercial development of the area now that commercial activity has been established in the area.

These alternative land uses, when implemented in E&P waste impacted areas, can result in negative agricultural, land development and regulatory outcomes ranging from reduced crop yield to crop failure, to excavation/surface exposure of E&P waste, to off-site transportation and to the commercial sale of E&P waste. E&P waste will remain on the Gastal tract that, in turn, will produce limitations on the viability of current and future land use scenarios.

There is no provision in the 29-B Regulations requiring deed recordation to permanently identify the presence of E&P waste on historical oil and gas properties. This increases the potential for E&P waste left on-site after completion of remediation activities to be unknowingly disturbed (excavated, transported off-site and sold) by future landowners, resulting in adverse exposure to the landowner, public and environment.

<u>Remediation Schedule and Environment</u>

The Petrodome Limited Admission Plan is also not in compliance with LAC 43:XIX.611.G. The Plan provides a remediation timeline including tasks inconsistent with the scope of remediation and estimated costs presented in the Plan. Specifically, the timeline includes a groundwater monitoring program to supposedly monitor groundwater quality beneath the Gastal tract for indications of groundwater contamination from Petrodome's produced water spill event. As discussed in previous sections, groundwater investigation/monitoring is necessary to complete the vertical delineation of produced water impacts from the spill event and evaluate the threat to groundwater quality in groundwater aquifers of the Chicot Aquifer Surficial Confining Unit and the Chicot Aquifer Upper Sand Unit. Groundwater investigation/monitoring should be added to the remediation scope and the estimated cost of that investigation/monitoring should be presented in the Plan.

<u>Appendix O – Alternate Plan Non-Compliance</u>

The Petrodome Limited Admission Plan includes Attachment O, titled "*Alternate Plan Regarding the Site Investigation Report and Proposed Remediation Plan*" (Alternate Plan). However, the

Alternate Plan also fails to comply with provisions of LAC 43:XIX.611.B, F and G in the following ways:

- It does not address compliance with 29-B Regulations for soil contamination beyond the limits of the proposed excavation (e.g. below 16 ft-bgs), even though there are documented exceedances of the EC standard to depths of at least 60 ft-bgs;
- The Alternate Plan proposes Monitored Natural Attenuation (MNA) of soil contamination in excess of 29-B Regulations beyond the limits of the proposed excavation (e.g. below 16 ft-bgs) without including any post closure monitoring to assess MNA effectiveness or future contaminant migration;
- It fails to recognize the presence of contamination migration pathways, the rapid migration of contaminants, and the threat to the underlying aquifers within the Chicot Aquifer Surficial Confining Unit and the Chicot Aquifer Upper Sand Unit;
- It fails to propose a groundwater investigation to determine the impact, if any, of produced water from the Petrodome spill event on groundwater quality;
- The Alternate Plan provides no provisions for verification that the proposed remediation is complete (i.e. no confirmatory samples);
- It fails to apply remediation standards protective of rice from environmental damage.
- The Alternate Plan fails to evaluate salt impacted soil on pore water quality in the crawfish burrow zone (approximately 0-4 ft-bgs) and fails to evaluate the effect of pore water conditions on crawfish reproduction, survival, and growth;
- It fails to provide a timeline for implementation of the alternate remedial program; and
- The Alternate Plan fails to provide a comprehensive itemized cost for the alternate remedial program. The alternate program proposes monitored natural attenuation (MNA) for soils below 16 ft-bgs. There is no itemized cost for implementation of MNA in the alternate remedial program cost estimate.

<u>Response to Section 1.5.1 Review of Plaintiff's Investigation</u>

The following comments are offered in response to the Petrodome Defendant's review:

<u>Bullet 1</u>: The Plan notes *"natural tolerances of EC as determined by the USDA as upward of two (2) mmhos/cm for the soil types encountered for the property…….*" The USDA has presented the natural tolerance as a ***range*** of EC for the soil types on the Gastal tract with a maximum of 2 mmhos/cm. This ***range*** represents EC measurements for those soil types over the entire area of occurrence, and 2 mmhos/cm is the ***maximum***. The site specific calculated

background EC proposed by the landowners is 1.2 mmhos/cm which lies within the USDA range.

Bullet 2: This comment fails to recognize the characteristics of a normally distributed (bell-shaped) dataset for background calculation and the utilization of one standard deviation. Approximately 68% of the background dataset falls within one standard deviation of the mean leaving 32% outside that range and evenly split above and below the range. Thus, 16% of the data points will be greater than the mean plus one standard deviation. In the dataset used by the landowners to develop background concentrations, less than 10 % of the data points were greater than the mean plus one standard deviation value of 1.2 mmho/cm.

Bullet 3: As previously noted, it is our understanding that the landowner, Danny Gastal, is not consenting to any exceptions necessary for utilization of RECAP. Exceedances of TPH and metals criteria in 29-B Regulations are not present.

Bullet 4: The presence of produced water impacts at least 60 ft-bgs beneath the Gastal tract proves the permeability and interconnectivity of soil/sediment beneath the Gastal tract and the viability of soil flushing as a remediation method. One consideration in performing soil flushing is the identification/delineation of produced water impacts, if any, to the first saturated zone within the Chicot Aquifer Surficial Confining Unit of the Chicot Aquifer as well as the necessity for groundwater remediation. Once the presence of groundwater contamination, if any, has been identified and the necessity for groundwater remediation determined, the soil flushing and monitoring program can be integrated with the groundwater remediation program, if necessary, for efficient remediation of the Gastal tract.

The landowners plan includes an investigation of the first saturated zone to determine the presence of groundwater aquifer impacts, if any, associated with the Petrodome Defendants produced water spill event. It is important to note the Petrodome Defendants Plan does include a task for implementing groundwater monitoring in the remediation timetable but excludes this task in the remediation scope of work and estimated costs.

If you have any questions, please do not hesitate to contact us.

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ATTACHMENT 1

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RBB
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Richard Brent Bray, P.G.

Title	Principal, RBB Consulting, LLC
Fields of Competence	Project management Strategic planning Geologic and hydrogeologic investigation Groundwater monitoring and recovery systems In-situ and ex-situ groundwater treatment systems Soil remediation RCRA and CERCLA compliance Property redevelopment (Brownfields) Risk assessment Construction remediation/demolition Litigation support
Professional Registrations & Affiliations	Registered Professional Geologist in the States of Louisiana (#400), Arkansas (#1722), Mississippi (#0375), and Tennessee (#TN1916, inactive) National Ground Water Association
Academic Background	Louisiana State University, Baton Rouge, Louisiana, 1989 **Master of Science in Geology**, specializing in Hydrogeology Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 1985 **Bachelor of Science in Geology**, Cum Laude

Professional Employment History

March 2014-Present:	RBB Consulting, LLC, Principal
July 2006-March 2014:	Sigma Environmental, Inc., Sr. Geologist
Aug. 2005-July 2006:	Benoit, Bray and Associates, Inc., Principal
Jul. 2004-Aug. 2005:	Sigma Engineers and Constructors, Inc., Sr. Geologist
Feb. 2003-Jul. 2004:	Ranger Environmental, Inc., Consultant
Apr. 2001-Feb. 2003:	Sabbatical: Self-Employed
Jan. 1991-Apr. 2001:	Environmental Resources Management Sept. 2000-Mar. 2001: Managing Partner, Mexico Operations Jan. 1996-Mar. 2001: Partner Jan. 1991-Dec. 1995: Senior Geologist
May 1987-Jan. 1991:	Dames & Moore, Staff Hydrogeologist

Environmental Consulting Experience

Litigation Support

Primary investigator supporting plaintiffs and defendants in litigation involving oil/gas exploration and production, petroleum refining, and petrochemical/manufacturing industries. Litigation support projects include:

- Principal for assessment, investigation and remediation design of oil/gas exploration/production properties in southwest Louisiana. Developed strategic plan for compiling historical and technical data to assess the impact of site activities on soil and groundwater conditions. Strategic planning included interpretation of aerial photography, identification of areas of concern, utilization of a Geographic Information System, design and implementation of field investigative programs, data analysis, and preparation of expert reports. Investigation results were compared to applicable regulatory standards as well as background conditions.

- Expert witness in geology, hydrogeology and site investigation to assess the impact of gas plant and separation station activities on soil, sediment and groundwater. Prepared expert report discussing geologic and hydrogeologic conditions including an assessment of the potential for contaminant migration into the Chicot Aquifer, a sole source drinking water aquifer in southwest Louisiana. Expert report also included a compilation of data regarding the installation and operation of two salt water disposal wells at the facility. Supervised field investigation activities and assisted in the preparation of a separate expert report addressing site investigation activities, delineation of contaminants (metals, petroleum hydrocarbon, chloride and Radium) in soil, groundwater, and sediment.

- Fact witness for a specialty chemical manufacturing facility in an insurance claim to recover investigation and remediation costs for chemical releases at a facility in Baton Rouge, Louisiana. Provided testimony in deposition regarding site conditions as well as current and historical remediation activities. Participation included presentation of soil, groundwater, and remediation data to corporate attorneys and legal staff to promote an understanding of technical strengths/weaknesses of datasets to be used in trial. Litigation resulted in a settlement in favor of the client.

- Designated expert witness for plaintiff in a claim regarding the extent and severity of environmental soil and groundwater contamination from historical railroad activities. Reviewed site investigation reports and risk assessment prepared by the defendants. Identified inconsistencies in site investigation techniques and reporting which led to inaccurate conclusions regarding site conditions.

- Prepared remediation scope of work and cost estimate as the designated expert for a property damage suit involving a former oil/gas pit and approximately 28 acres of canals containing contaminated sediment from oil/gas production activities. The remediation cost estimate included production pit excavation; dredging, dewatering, solidification, and off-site disposal of approximately 98,000 cubic yards of contaminated sediment and groundwater remediation to remove inorganic contaminants.

- Provided technical assistance to defendant counsel in assessing the adequacy of site investigation activities and remediation scoping/cost estimation for an oil/gas property containing production wells and storage facilities.

- Designated expert in litigation regarding property damage associated with the migration of groundwater contaminated with hazardous constituents (organic compounds) from a National Priorities List site onto the plaintiff's property as a result of a regulatory approved remediation program based on natural attenuation.

- Performed initial site inspections of 3 oil/gas properties in south Louisiana focused on documenting current site conditions, providing an inventory of the visible impacts to the property and collection of soil samples in areas potentially affected by site activities for comparison to regulatory standards. Prepared a preliminary site inspection report for each site and provided deposition on current conditions at one of the properties.

- Prepared remedial scope of work and cost estimate as the designated expert for property affected by petroleum spills from an adjacent fuel storage facility. The cost estimate included soil remediation of pastureland and residential properties as well as remediation of sediments within a pond affected by the petroleum spill.

- Provided technical support to a refinery in southeast Louisiana defending a suit claiming damage to adjacent properties as a result of historical waste disposal practices. Tasks included compilation/interpretation of historical aerial photographs documenting the growth of the refinery and adjacent neighborhoods over more than 50 years, assessment of plaintiff site characterization data and evaluation of supplemental data collected as part of the defense process.

- Litigation support and deposition for the former owner of a metal manufacturing facility in defense of a claim by a subsequent owner regarding the representation of environmental conditions at the time of purchase. Provided technical support regarding soil and groundwater investigation activities as well as remedial action planning for the facility maintenance shop which had been identified as a source of solvent contamination.

- Provided technical and environmental compliance support for corporate counsel of a shipyard/marine construction company in southeast Louisiana addressing violations of the Clean Water Act as well as solid and hazardous waste regulations.

Oil and Gas Industry

Provided environmental consulting, site investigation, and construction remediation services to clients involved in the exploration and production aspects of the petroleum industry. Projects included:

- Soil and groundwater investigation of an inactive brine pit associated with oil/gas production in Jennings, Louisiana. Investigation activities included the use of geophysics and cone penetrometer technology in conjunction with standard drilling techniques to define the limits and migration direction of brine contamination in soil and ground water.

- Investigation of a drilling fluid mixing facility in Dulac, Louisiana to assess the presence of site constituents in soil as part of a facility upgrade program. The project included identification of areas affected with organic (petroleum hydrocarbon) and inorganic (metals including hexavalent chromium) constituents. Developed a remediation plan to remove affected soil and concrete associated with mixing and storage areas.

- Assessment of an inactive pipe yard used for cleaning, maintenance and storage of drilling rods and pipe in Harvey, Louisiana. Investigation included completion of a survey for naturally occurring radioactive material (NORM) which was the primary constituent of concern at the facility as well as an assessment of soil affected with solvents, lubricants and petroleum hydrocarbons.

- Closure of a sunken barge associated with historical drilling fluid mixing activities in Dulac, Louisiana. Developed and implemented a closure plan including demolition and disposal of the overlying concrete pad contaminated by historical use of hexavalent chromium, removal of the barge deck, decontamination of the hull, backfilling of the barge hull, and construction of a concrete pavement over the barge to provide additional equipment and material storage area for the facility.

- Preparation of SPCC plans for drilling fluid mixing facilities in Louisiana and Alabama. Plans were submitted to the U.S. Coast Guard and when necessary, USEPA for approval.

- Performed an evaluation of air emissions from drilling fluid mixing facilities in Louisiana and Alabama to determine the necessity for obtaining air permits/exemptions for each facility.

Petroleum Refining Industry

Principal-in-Charge for environmental consulting, site investigation, risk assessment and construction remediation to clients involved in the refining aspects of the petroleum industry. Projects in southeast Louisiana have included:

- Inspection and upgrade of the facility ground water monitoring network including well replacement and repair to achieve compliance with well construction regulations. Prepared and obtained regulatory approval of ground water monitoring plans for solid and hazardous waste units. Implemented the ground water monitoring program in accordance with the facility solid waste permit, hazardous waste regulations, and facility monitoring plans.

- Performed investigations to evaluate the historical affect of site operations on soil and ground water quality prior to construction activities. At required locations, a remedial plan involving removal of affected soil, confirmation sampling, and ground water monitoring was prepared and approved by the regulatory agency. Supervised all remediation operations and prepared reports for submittal to the regulating agency.

- Completed soil, sludge and groundwater characterization activities within and surrounding a wastewater basin as well as performed a leachability study of lead affected soil stockpiled within the facility. A risk-based closure plan utilizing the stockpiled soil as backfill material was prepared and approved by the regulatory agency. Implementation of the plan saved more than $1,000,000 in waste disposal fees.

- Designed and implemented a sludge, soil and ground water investigation program at the inactive hazardous waste land treatment unit to evaluate waste depth/degradation, underlying soil conditions and shallow ground water quality. Once completed, a risk based closure plan was prepared focusing on relocating waste material to a single unit. This allowed re-use of the remediated area for future refinery construction. In addition, the plan included the installation of a cap over the new waste area that would be in compliance with applicable regulations and allow re-use of the area once the project was complete.

- Sludge sampling of a non-contact cooling water pond to evaluate the regulatory status of the unit and development of construction plans/costs for sludge removal and disposal.

Petrochemical Industry

Principal-in-Charge for strategic assessment of remediation activities at a specialty chemical facility in Baton Rouge, Louisiana which was utilizing pump & treat technology and aerobic wastewater treatment to address multi-aquifer organic contamination. Developed an aggressive plan to refocus the remediation program and bring activities to a cost effective conclusion via risk-based closure. Tasks completed in this project included:

- Successful negotiation with state regulatory agency to reduce the groundwater monitoring program by 80%. This resulted in a cost savings of approximately $100,000/year.

- Assessment of historical remediation actions and the existing ground water monitoring database for use in a risk-based closure of the facility.

- Design and implementation of a soil and groundwater investigative program to collect additional data for evaluating current site conditions and supplementing the database for risk based closure.

- Successful negotiation with the regulating agency to shutdown the groundwater recovery system and wastewater treatment plant to evaluate groundwater quality and flow under natural conditions. System was subsequently decommissioned which resulted in project savings of more than $100,000/year.

- Supplemental soil and groundwater investigation activities to delineate areas of elevated contaminant concentrations ("hotspots") and address an off-site area of affected groundwater identified in the initial investigation.

- Design and implementation of a pilot study utilizing in-situ aerobic biodegradation to address hotspots. The pilot study was based on air sparging techniques and utilized piping associated with the historical ground water recovery system to reduce costs by more than 85%. Successful completion of the pilot study resulted in full deployment of two air sparge systems with one system addressing multi-aquifer contamination and utilizing fractures within the soil to increase the degradation rate of site constituents. Remediation costs associated with full system deployment were significantly reduced by re-conditioning the existing groundwater recovery system for use in the air sparge system. The success of the in-situ treatment system resulted in the development of a risk-based closure for the facility.

- Interfaced with the regulatory agency to obtain approval of the revised remedial program. Maintained open communications with updates on current results and upcoming activities. Successfully maintained voluntary action status for the remedial program and avoided any administrative actions.

Principal-in-Charge for site assessment activities at a lubricant blending facility in Mexico City, Mexico. Assessment activities included investigation and delineation of soil and groundwater affected with petroleum hydrocarbons, identification of source areas, and risk assessment to evaluate the potential risk to human health and the environment.

Site supervisor of closure construction activities for solid waste impoundments at an inactive plastics manufacturing facility in Baton Rouge, Louisiana. Remediation activities included dewatering and solidification of sludge with subsequent on-site landfilling, monitoring of stormwater/wastewater quality prior to discharge, and final grading of impoundments encompassing more than fifteen acres.

Property Redevelopment (Brownfields)

Provided senior consulting services to identify and resolve environmental issues associated with Brownfield redevelopment of commercial/industrial properties. Redevelopment projects have included:

- Senior technical manager responsible for addressing environmental and construction issues associated with the commercial redevelopment of a former battery recycling facility within the Central Business District of New Orleans, Louisiana. Responsibilities included strategic planning using risk based programs, management of investigation/remediation activities, interaction with client and regulatory representatives, and quality assurance/quality control.

- Project manager for investigation, risk assessment, remediation, and closure of a former metals recycling facility affected with inorganic and organic constituents including PCBs. The facility encompassed three city blocks adjacent to the Central Business District of New Orleans, Louisiana with the project focused on commercial redevelopment of the area by a Fortune 500 Company.

- Project manager for evaluating soil and groundwater contamination associated with historical underground storage tanks beneath a new commercial building constructed as part of a property redevelopment program in Metairie, Louisiana. Regulatory agency concerns regarding the affect of soil and groundwater contamination on indoor air quality prohibited the facility opening. Supplemental sampling confirmed the lack of risk to customers and employees and identified an adjacent auto service station as the off-site source for petroleum contamination. The facility subsequently received approval from the regulatory agency to open.

- Project manager for assessing the impact of redeveloping property formerly used as an auto service center with known soil and groundwater contamination from underground storage tanks. Because petroleum hydrocarbon concentrations were sufficient to warrant groundwater and indoor air quality concerns, construction had been stopped by the regulatory agency. The project involved the re-design of the building foundation to include an impermeable barrier beneath the new structure as an engineered control to prevent hydrocarbon vapors from entering the building. The plan was approved by the regulatory agency allowing construction to continue.

- Project manager for assessment of property formerly containing underground storage tanks and being redeveloped for commercial use. Designed and implemented a soil investigation to evaluate current site conditions. Interfaced with the regulatory agency to address residual contamination which could not be removed due to the proximity of the contamination to a state highway and utilities. Obtained LDEQ RECAP closure with no further action at this time.

CERCLA Sites

Principal-in-Charge for investigation, risk assessment, closure and post-closure design, and compliance monitoring of the Alsco Anaconda NPL site in Gnadenhutten, Ohio, a former aluminum recycling facility affected by metals and PCB contamination. Activities included:

- Design and implementation of an investigative program to identify site constituents in soil, groundwater, sludge, and the adjacent Tuscarawas River. Activities included preparation of project documents such as the Field Sampling Plan, Health and Safety Plan, Quality Assurance Program Plans, etc. for U.S. EPA Region V review and approval. Investigation results provided a basis for risk-based closure of the site.

- Completion and EPA approval of a human and ecological risk assessment in order to establish clean-up standards.

- Design and implementation of a geophysical investigation to identify buried drums within a portion of the site which had been used for waste disposal. Developed and implemented a drum handling program for the excavation, overpacking, characterization, and off-site disposal of buried drums.

- Design and regulatory approval of a Remedial Action Program including all supporting documentation such as construction specifications, construction bid documents, Remedial Work Plan, Field Sampling Plan, Health and Safety Plan, Quality Assurance Plan, and Post-Closure Monitoring Plan.

- Implementation of the approved remedial action which included:

    - Excavation, dewatering, solidification and off-site disposal of more than 49,200 tons of hazardous and solid waste,
    - Treatment and discharge of 360,000 gallons of wastewater,
    - Excavation, characterization and disposal of more than 90 drums,
    - Confirmation sampling,
    - Placement and compaction of almost 11,000 cubic yards of backfill and
    - Final grading and seeding of the site for use as a wildlife area.

- Prepared and received regulatory approval of the Closure Certification Report documenting the successful completion of the risk-based closure.

- Designed and implemented a post-closure monitoring program for installation/sampling of monitor wells and ecological monitoring of the Tuscarawas River.

Staff hydrogeologist performing site investigation and data management for investigation/remediation activities at the Petro Processors NPL Site in Scotlandville, Louisiana.

Biomedical Research Facility

Senior manager for investigation and remediation of former waste disposal areas. Activities included identification, classification, and disposal of surface material composed of office and laboratory equipment including primate cages which were handled as potentially infectious biomedical waste. Subsurface investigation activities utilized geophysics and test trenching to identify locations where laboratory waste was buried on-site. Waste was excavated, sorted and either disposed off-site as potentially infectious biomedical waste or disinfected on-site following state health regulations and disposed off-site as solid waste.

Project manager for investigation, characterization, and remediation of incinerator ash commingled with office, laboratory, and building demolition debris in an area designated for future construction activities. Debris was located on a river bank and immediately adjacent to structures currently in use at the facility. Investigation included waste delineation and characterization for disposal. Remediation included plan development and implementation to remove waste material without endangering the structural integrity of adjacent buildings.

Assisted in the preparation of facility LPDES Permit addressing wastewater outfalls associated with research facility operation as well as stormwater discharges from a primate breeding facility with a population in excess of 3,000 primates. To achieve LPDES requirements, identified alternative disposal methods for liquids generated by the research facility and worked with facility personnel and state regulators in the characterization and classification of wastewater impoundments.

Project manager developing the scope of work and estimated cost for maintenance of the primary wastewater sump and three wastewater ponds within the wastewater treatment system. The primary focus of sump maintenance was to inspect the integrity of the sump and associated piping as well as removal of sludge and any medical sharps (i.e. needles, scalpels, etc.) which accumulated in the bottom of the structure. Pond maintenance focused on sludge removal including the excavation, disinfection and dewatering of approximately 2,500 cubic yards of sludge while controlling sludge odor to limit the impact on adjacent property owners including an elementary and secondary school.

Project manager for repair and assessment of historical water supply wells discovered during facility expansion. Repaired well heads to eliminate leakage resulting from artesian conditions and upgraded surface completions to comply with state regulatory standards. Performed flow testing to determine well discharge under artesian conditions, sampling to determine water quality, identified the water supply aquifer, and evaluated suitability of the wells for integration into the facility water supply system.

Project manager of initial assessment activities for demolition of a radiation building associated with nuclear research activities. Assessment activities included review of historical aerial photography and site walkover to identify/inspect the radiation building and remaining support structures. Developed scope of work with subcontractors licensed to dismantle and handle radiation affected waste materials.

Shipyard/Marine Construction

Senior manager providing permitting and compliance monitoring to a shipyard/marine construction company. Activities include development of Spill Prevention Control and Countermeasure, Facility Response and Storm Water Pollution Prevention Plans, implementation and documentation of LPDES monitoring activities, preparation of site investigation plans, preparation of air permits, and interaction with the regulatory agency.

Manufacturing Industry

Principal-in-Charge for demolition of a transite manufacturing facility in New Orleans, Louisiana. Activities included asbestos removal/disposal, building demolition, steel recycling, PCB/petroleum hydrocarbon affected soil remediation, air monitoring, remediation of an off-site asbestos waste disposal area and successful negotiation with state and federal agencies to expedite project implementation and completion.

Project manager for soil/groundwater investigation and remedial action planning of solvent contamination associated with maintenance shop activities at a metal fabricating facility in Shreveport, Louisiana.

Principal-in-Charge for assessment of site investigation and facility decommissioning activities at a former battery manufacturing facility in Naucalpan, Mexico. Activities included a review of historical investigation activities, soil and groundwater sampling, confirmation sampling after building decontamination and delineation of remaining remediation activities in order to complete facility closure.

Project manager for soil and groundwater assessment of a forklift maintenance/repair facility in Metairie, Louisiana to evaluate the accuracy of historical investigation results and assess the limits of affected soil and groundwater using risk based standards identified in the Louisiana Department of Environmental Quality Risk Evaluation Corrective Action Program.

Project manager for groundwater monitoring program at a paper products facility in north Louisiana. Project was implemented as part of the facility solid waste permit and included groundwater sampling, historical data review and statistical data analysis.

Site project manager for the installation of a groundwater recovery system in northern Illinois. Responsibilities included characterization of the glacial aquifer affected by facility operations, recovery well design, air rotary drilling and well construction.

Commercial Airline Industry

Site manager for field operations at an aircraft maintenance facility in Tulsa, Oklahoma. Responsibilities included the planning and implementation of a soil and groundwater investigation for an inactive metal plating and hazardous waste facility as well as completion of a facility wastewater study. Performed assessment of existing facility ground water monitoring network including data management and interpretation of historical groundwater quality records.

Publications:

Hanor, J.S., Bray, R.B. and Nunn, J.A., 2007 *"Interaction Between Topographic, Thermohaline, and Overpressured Flow Regimes in the South Louisiana Gulf Coast"* Geological Society of America Abstracts with Programs, Vol. 39, No. 6, p. 267.

"Spatial Variations in Subsurface Pore Fluid Properties in a Portion of Southeast Louisiana: Implications for Fluid Migration and Solute Transport", Gulf Coast Association of Geological Societies, 1990, p. 53-64.

Cambro-Ordivician Passive Margin for the U.S. Appalachians Isopach Map Illustrations, Geology of North America, Appalachian – Ouachita Orogen of the United States, Volume F2.

2020 - 2025 Litigation Case List
R. Brent Bray, P.G.

Case	Year	Description
Barnes et al vs. Dresses LLC et al U.S. District Court, Western District of Louisiana	2024-Present	MFP Comments
Wil-O's, LLC, et al vs. Boardwalk Louisiana Midstream, et al 18th J.D.C., Parish of Iberville, State of Louisiana Docket No. 082639, Division C	2023-Present	Affadavit, Deposition
Sam R. Aertker vs. Dresser, LLC, et al 19th J.D.C., Parish of East Baton Rouge, State of Louisiana Docket No. C-702370, Division 21	2021-Present	Expert Report, Affadavit
H.C. Drew Estate vs. Neumin Production Company,et al 14th J.D.C., Parish of Calcasieu, State of Louisiana Docket No. 2019-4925-F	2021-2024	Expert Report, Deposition
Woodbrook, Inc, et al vs. Anadarko Petroleum Corporation, et al 14th J.D.C., Parish of Calcasieu, State of Louisiana Docket No. 2018-5201	2018-2022	Expert Report, Deposition
The Salvation Army et al vs. Union Pacific Railroad Company, et al 15th J.D.C., Parish of Lafayette, State of Louisiana Docket No. 2016-0548-F,	2016-Present	Expert Report

DUANE PIRANIO, P.G.

EDUCATION

Louisiana Tech University, B.S., Geology, 1985
U. S. Naval Oceanographic Office Hydrographic Training, 1987

PROFESSIONAL HISTORY

2003-Date	Geologist, Arabie Environmental Solutions, LLC/Southland Environmental, LLC
1995-2003	Geologist/Project Manager, Handex Group, Inc.
1987-1994	Seismologist, Halliburton Geophysical Services, Inc.
1987	Hydrologist, U.S. Naval Oceanographic Office

PROFESSIONAL REGISTRATION

- Louisiana Licensed Geoscientist No. 273
- North Carolina Licensed Geologist No. 1659
- Texas Licensed Professional Geoscientist – Geology No. 10093
- Tennessee Registered Geologist No. 4394

PROFESSIONAL ORGANIZATIONS

- Gulf Coast Association of Geological Societies
- Baton Rouge Geological Society

COMMUNITY SERVICE

- Lake Charles Happy Hour Rotary Club – 2021 – Present
- Southwest Louisiana Law Center – Board Member, 2021- Present (Current Chair);
- Volunteer Center of Southwest Louisiana – Board Member and Committee Chair, 2010-2012
- Leadership Southwest Louisiana – Graduate, 2010
- Southwest Louisiana Economic Development Alliance Environmental Affairs Committee Volunteer – 2010-Present

REPRESENTATIVE EXPERIENCE

Mr. Piranio has more than 36 years of geological work experience in industrial, government and litigation settings. He has designed and managed soil/groundwater investigation and remediation projects related to bulk fuel terminals, port facilities, interstate pipelines, petroleum exploration/production sites, and underground storage tank facilities. Mr. Piranio has completed these projects in the states of Florida, Louisiana, North Carolina, South Carolina, Tennessee, Texas, and Virginia. His investigation experience includes monitor/recovery well design and installation, as well as design and implementation of aquifer characterization studies. His remediation experience includes pilot testing and system operation, maintenance and monitoring using a variety of technologies, including in-situ chemical oxidation, monitored natural attenuation, groundwater pump and treat, soil vapor extraction, air sparging, contaminant modeling, as well as soil excavation and disposal. Mr. Piranio has performed American Society for Testing and Materials' (ASTM) Phase I and Phase II Environmental Site Assessments, ASTM Risk Based Corrective Action evaluations, Louisiana Department of Environmental Quality Risk Evaluation/Corrective Action Program evaluations, and Louisiana Department of Natural Resources Statewide Order 29-B compliance in a variety of geologic settings. His involvement in these projects has been from the planning and budgeting phase through data analysis and report preparation, including expert testimony when requested.

Mr. Piranio has held responsibility for the operation, maintenance and monitoring of numerous soil and groundwater remediation systems, including a RCRA Superfund groundwater remediation site in North Carolina. He has managed regional portfolios of UST and bulk fuel terminal sites for multiple clients, with turn-key responsibilities from initial planning to site closure.

Mr. Piranio performed risk assessments and developed Emergency Response Plans for local parish and city water supply and wastewater treatment facilities for U. S. Environmental Protection Agency compliance. His permitting experience ranges from preparation of an underground injection/commercial saltwater disposal facility application, Coastal Use Permits, and surface water discharge permits in Florida, Louisiana, North Carolina, and Virginia. His work often includes interpretation and application of regulatory requirements.

Prior to entering the environmental industry, Mr. Piranio acquired over seven years of petroleum geophysical industry experience in 2-D and 3-D reflection and refraction seismic data acquisition, processing, and interpretation in the Gulf of Mexico and Middle East.

LITIGATION CASE LIST

Case	Year	Description
Domatti M.A. Management Trust vs Lessley Services, LLC, et al 38th Judicial District Court, Cameron Parish, Louisiana Docket No. 10-20432	2019-2021	Expert Report, Deposition, Trial Testimony
James Steven Broussard, et al, vs Mayne & Mertz, Inc, et al 14th Judicial District Court, Calcasieu Parish, Louisiana Docket No. 2018-2721	2020-2021	Expert Report, Deposition
H. C. Drew Estate vs. Neumin Production Company, et. al. 14th Judicial District Court, Calcasieu Parish, Louisiana Case No. 2019-4925-F	2019-2022	Expert Report, Deposition
Woodbrook, Inc., et. al. vs. Anadarko Petroleum Corporation, et. al. 14th Judicial District Court, Calcasieu Parish, Louisiana Case No. 2018-5201,	2022	Expert Report, Deposition
Danny Paul Gastal, et al vs. Petrodome Operating, LLC, et. al. 15th Judicial District Court, Acadia Parish, Louisiana Case No. 202210495-A	2022 - To Date	Expert Report, Deposition

The Lacassane Co., Inc vs. BP America Production Co., et. al. 38th Judicial District Court, Cameron Parish, Louisiana Case No. 10-20196	2018	Ongoing Investigation
Twin Creeks Drilling, LLC vs Darren Noel and Jena DuRousseau Lake Charles City Court – No. 23-345	2023-2024	Report, Trial Testimony

ATTACHMENT 2

STATE OF LOUISIANA
DEPARTMENT OF NATURAL RESOURCES
OFFICE OF CONSERVATION

IN RE: **DOCKET NO. ENV-L-2013-02**

Agri-South, L.L.C., et al. v.
Exxon Mobil Corporation, et al.
Docket No. 24,132,
Seventh Judicial District Court,
Parish of Catahoula

LOUISIANA DEPARTMENT OF NATURAL RESOURCES, OFFICE OF CONSERVATION'S WRITTEN REASONS IN SUPPORT OF MOST FEASIBLE PLAN AS REQUIRED BY LA. R.S. 30:29

I. INTRODUCTION

On January 25, 2013, Tensas Delta Exploration Company, L.L.C. ("Tensas Delta") admitted responsibility for certain environmental damage, and accepted responsibility for that damage under Louisiana Code of Civil Procedure Article 1563.[1] In its Limited Admission, "Tensas Delta admitted that 'environmental damage'... exists with respect to the soil and shallow groundwater, as delineated in [its] attached plan." (Limited Admission, ¶4). It further stated that "*Tensas Delta's admission of liability is limited to the 'responsibility for implementing the most feasible plan to evaluate, and if necessary, remediate' the soil and shallow groundwater* in the area associated with the operation of SN 164189 and SN 159595 to regulatory standards." (Limited

[1] La. C. Civ. Proc. Art. 1563 (A)(1), enacted in 2012 by Act No. 754 (H.B. No. 618), in pertinent part, provides—

> If any party admits liability for environmental damage pursuant to R.S. 30:29, **that party may elect to limit this admission of liability for environmental damage to responsibility for implementing the most feasible plan to evaluate, and if necessary, remediate all or a portion of the contamination that is the subject of the litigation to applicable regulatory standards**,

(hereinafter referred to as a "Limited Admission").

Admission, ¶5) (Emphasis in italics added). On the same date, Tensas Delta submitted a plan of remediation to the Louisiana Department of Natural Resources, Office of Conservation (hereinafter "**LDNR**", "**Conservation**", and/or "**Agency**").[2] The Court, on February 27, 2013, ordered any interested party to provide to LDNR any alternative plan, comments, or response to the Tensas Delta plan by April 30, 2013. An alternative plan was timely submitted by Plaintiff, Plug Road, LLC ("Plug Road") on April 29, 2013.[3]

Pursuant to La. R.S. 30:29 (C) (2) (2012), LDNR/Conservation/Agency held a public hearing spanning nine hearing days, Monday through Friday, August 5-9, 2013, and Tuesday through Friday, August 13-16, 2013. LDNR employees with relevant technical backgrounds[4] sat as a panel and considered the evidence. The evidence consisted of testimony from experts, eight offered by Tensas Delta and three offered by Plug Road,[5] and numerous exhibits including data, maps, and historical studies.[6] After the hearing, both sides submitted post-hearing briefs.

LDNR/Conservation/Agency has decided neither plan is acceptable as presented. It has structured its own plan which it is submitting to the Court. Its plan is a "feasible plan" within the

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[2] The "Tensas Delta Site Investigation Report and Remediation Plan A-1 Area Plug Road Property, South Shoe Bayou Field Catahoula Parish, Louisiana," dated January 24, 2013, and submitted to LDNR on January 25, 2013, was introduced at the public hearing on August 5, 2013 as **TD-DNR Exhibit 1** (hereinafter "TD Plan"). An Addendum to that plan, dated July 10, 2013, was introduced at the hearing on August 5 as **TD-DNR Exhibit 2**. (hereinafter "TD Addendum").

[3] The "Agri-South Group, LLC Investigative and Corrective Action Plan Plug Road Tract, South Shoe Bayou Field," dated April 29, 2013, and submitted to LDNR on that date, was introduced at the hearing as **AGS 1** (hereinafter AGS Plan").

[4] See **Exhibit 1 to Written Reasons (Panelists and Their Backgrounds)** attached hereto.

[5] See **Exhibit 2 to Written Reasons (Expert Witnesses who Testified)** attached hereto. The exhibit summarizes academic training, current employer, and area tendered and accepted.

[6] Tensas Delta introduced thirty-five (35) exhibits (exclusive of its final list of exhibits, which is **TD-DNR Exhibit 36**), and Plug Road introduced seventy-three (73) exhibits (exclusive of its final list of exhibits, which is **AGS 74**).

meaning of La. R.S. 30:29 (I)(3) and LAC 43:XIX.603, and the "most feasible plan" within the meaning of La. R.S. 30:29 (C)(2)(a), (3)(a) & (3)(b)(ii) and LAC 43:XIX.627.A.

These written reasons are issued in compliance with La. R.S. 30:29 (C)(2) & (3) and LAC 43:XIX.627.A.

II. BURDEN OF PROOF AS TO THE ALLUVIAL AQUIFER

The issue of who has the burden of proof as to alleged contamination in the Red River Alluvial aquifer was raised in closing arguments and in post-hearing briefs because Tensas Delta ***has not admitted responsibility for elevated chloride levels detected in the Red River Alluvial aquifer*** beneath the Plug Road property.[7]

LDNR does not believe that burden of proof is a consideration in its selection or structuring of the most feasible plan.[8] The most feasible plan can, and does, address the alluvial aquifer

[7] Plug Road challenged LDNR's authority to even hear evidence as to environmental damage to the alluvial aquifer groundwater in a motion in limine filed prior to the start of the hearing. It contended that since the Tensas Delta Limited Admission was **only** for environmental damage to soil and shallow groundwater, LDNR had no authority to take evidence on this point. The motion was denied in a written ruling before the hearing began. This point was taken up, and arguments heard, at the start of the hearing; and, it again has been raised in Plug Road's post-hearing brief, contending that any ruling by LDNR/Agency would be an improper advisory opinion. LDNR does not view La. C. Civ. Proc. Art. 1563 (A)(1) (the "limited admission" provision) as constraining it from considering whatever evidence it deems relevant in arriving at the most feasible plan, and that is particularly so where, as here, the shallow groundwater is admittedly contaminated and is admittedly in direct hydraulic communication with the alluvial aquifer. *See* argument, constituting an admission, of Mr. Buatt on this issue at the start of the hearing, 8/5/13, @ Vol.1, pp. 12-13. *See also* TD Plan, n. 2, *supra*, Section 6.2.3.1 ("No Action"), stating "the shallow groundwater is hydraulically connected to the RRVA." *See also* Stover testimony, 8/5/13, @ Vol. 1, pp. 121, 187, where Mr. Stover states that "the shallow groundwater's in direct communication with the lower aquifer." Both parties agreed that the alluvial aquifer (the Red River Alluvial aquifer, referred to sometimes as the "RRVA") has elevated chloride levels beneath Plug Road, but Tensas Delta contends that the source of that elevated chlorides is "natural", coming up from below, from a tertiary aquifer known as the Williamson Creek aquifer. Plug Road contends that a clay layer completely separates the RRVA from the Williamson Creek aquifer, so E&P activities had to have caused the high chlorides in the RRVA.

[8] The panel appreciates, and has considered, both sides' positions on burden of proof, which are ably set forth in their post-trial briefs. See **Post –Hearing Brief on Behalf of Tensas Delta Exploration Company, LLC**, served on

issue, and it does not constitute an improper advisory opinion merely because Tensas Delta has chosen not to admit responsibility as to the alluvial aquifer. Tensas Delta included the alluvial aquifer issue for LDNR/Agency's consideration. Its plan includes a groundwater monitoring proposal that provides for some monitoring in the alluvial aquifer.[9] In addition, many of the Tensas Delta witnesses were testifying specifically to establish that the elevated chlorides in the alluvial aquifer were not from E&P activities.[10]

In any event, the evidence on the issue of the source of elevated salt in the alluvial aquifer was neither comprehensive nor conclusive for either side, and the most feasible plan requires further sampling and monitoring.

III. **SOIL REMEDIATION**

The TD Plan and AGS Plan identify two AOIs where E&P activities were conducted from about 1978 to 1985.[11] The information provided to LDNR at the hearing clearly established that

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August 23, 2013, Section II, at pp. 2-4; and the **Landowner's Post-Trial Brief**, served on August 23, 2013, at pp. 1-2.

[9] In the TD Plan, n. 2, *supra*, Section 7.3 ("Groundwater Monitoring Plan"), it states: A groundwater monitoring network will be established to determine groundwater condition over a five-year time period. The groundwater monitoring network will also aid in determining the effectiveness of the soil removal and treatment as protection of the shallow groundwater and the RRVA. *Groundwater monitoring wells will be installed in specific locations to monitor source areas in* both the shallow groundwater stratum and *the RRVA*." (Emphasis in italics added). *See* Mr. Stover testified at the hearing about this proposed groundwater monitoring in the alluvial aquifer. Stover testimony, 8/5/13, Vol. 1, at pp. 190-95.

[10] That was the sole purpose of the testimony of Mr. Stover, Dr. Reynolds, and Dr. Kueper. It was in part the purpose of Mr. Bazer's and Dr. Warner's testimony. While not a major part of Mr. Upthegrove's testimony, he compiled the work of all TD experts into the TD plan put together by Michael Pisani & Associates, Inc., and he mentioned the issue. Mr. Austin's testimony also touched on the issue. The only Tensas Delta witness that did not touch on the alluvial aquifer issue in any way was Mr. Daigle, whose testimony was confined to soil contamination entirely.

[11] The two Areas of Investigation ("AOIs") are referred by the parties as AOI South and AOI North. **AOI South** is located in the vicinity of SN159595 (T-125), Spud date 6/12/1978, Producer, P&A 11/12/1985. **AOI North** is

soil in, around, and below these former exploration and production locations at the Plug Road property exceeds applicable salt parameters— most notably, electrical conductivity ("EC"), the most commonly referenced salt standard for soils under Statewide Order 29-B, of 4 mmhos/cm for upland areas [12]—in the soil to a depth of at least 30 feet below ground surface.[13]

The TD Plan proposes to remediate the salt-impacted soil as follows:

1) excavate and dispose of soil with electrical conductivity (EC) exceeding 10 mmhos/cm to a depth of three (3) feet below ground surface;

2) treat salt-impacted soil with gypsum, hay, and nitrogen fertilizer in one foot layers to a depth of three (3) feet below ground surface where the EC results >4 mmhos/cm and <10 mmhos/cm and return the treated layers to the same soil horizon;

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located in the vicinity of SN164189 (T-133), Spud date 8/2/1979, Dry hole, converted to SWD 10/1/1979, and P&A 11/12/1985. *See* TD Plan, n. 2, *supra*, Section 2.3.1 ("Oil & Gas Wells") and Section 3.0 (Site Investigation Activities"); and AGS Plan, n. 3, *supra*, Section 2.0 ("Site Description and History"). The wells can be seen on Figure 4, the 2010 Aerial Oil and Gas Well Location Map attached to the AGS Plan. According to the TD Plan, two pits are associated with SN159595 (AOI South) and can be seen in aerial photographs in the early 1980s, but both appear to be closed by September 1985. According to the TD Plan, no pits associated with SN164189 (AOI North) are readily discernible on the aerials. *See* TD Plan, n.2, *supra*, Section 2.3.2 ("Surface Facilities"). But, this "dry hole" well was converted to a salt water disposal well, and "produced water" from E&P operations was injected downhole through this period before it was ultimately plugged and abandoned in 1985.

[12] LAC 43:XIX.313.D.3.

[13] *See* AGS Plan, n. 3, *supra*, Section 4.2.2 ("Electrical Conductivity Profiling"), stating that "[e]xamination of the conductivity probe profiles indicates salt impacts extend to depths exceeding 30 feet below ground surface near the former pit." *See also* Arabie testimony, 8/15/13, @ Vol. 8, pp. 160-61 & associated slide, **AGS 68**, PowerPoint slide 18, depicting elevated EC values at AOI South to a depth greater than thirty (30) feet. TD experts acknowledge excessive salt to depths far greater than three feet, which is the depth to which TD proposes to remediate the soil. *See* Upthegrove testimony, 8/8/13, @ Vol. 4, pp. 206-07, where he acknowledges salt impacts of the soil down to (20) feet; and Daigle testimony, 8/9/13, @ Vol. 5, pp. 164, where he also acknowledges that salt contamination in the soil extends to "around twenty feet in some spots" based on data collected by Tensas Delta experts. Mr. Daigle, the primary soil expert for Tensas Delta, acknowledged that he didn't have any reason to believe Mr. Arabie's and Mr. Bray's test results were incorrect. *Id. See also* TD Plan, n. 2, *supra*, Section 3.2 ("AES Investigation"), 3.2.1 ("Electromagnetic Conductivity Survey and EC Probing"), stating that the AES advanced conductivity probe logs "indicate elevated conductivity results in EC probe 19040502 to a depth of just greater than 30 bls." Mr. Upthegrove responded to questioning about TD Plan, Section 3.2, and said he did not have any reason to believe that the results of AES were wrong or inaccurate. *See* Upthegrove testimony, 8/9/13, Vol. 5, @ p. 13.

3) place a gypsum layer and then a six-inch thick continuous capillary break below the treated soil (three feet below ground surface);

4) leave soil below the capillary break undisturbed;

5) backfill any excavated areas with Sharkey clay;

6) re-vegetate surface of remediated area;

7) collect confirmation samples of treated material during and one (1) year following completion of soil remediation activities, and additional soil samples as needed;

8) establish groundwater monitoring network to aid in determining the effectiveness of the soil removal and treatment; and

9) within sixty (60) days from completion of a two-year post-remediation monitoring/vegetative recovery, provide detailed report to LDNR for review.[14]

The AGS Plan, on the other hand, suggests that complete removal of salt-impacted soil down to the first continuously saturated zone or twenty (20) feet, whichever is shallower, may be necessary,[15] but the plan actually indicates that the salt parameter exceedances under 29-B are only to average depths of eleven (11) feet at the South AOI and seven (7) feet at the North AOI respectively.[16] The AGS Plan presents a table in Section 12.3.1 that only proposes cleanup to these eleven (11) and seven (7) foot depths.[17] The AGS Plan is a classic "dig and haul", and

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[14] *See* TD Plan, n. 2, *supra*, Section 7.2 ("Soil Remediation"). This section of the plan details all of the items listed.

[15] *See* AGS Plan, n. 3, *supra*, Section 10.2.1 ("Section 313.-Land Treatment"). This Plan refers to literature documenting plant roots of various species, most of which substantially exceed three feet, and some of which are grown on the Plug Road property.

[16] *See* AGS Plan, n. 3, *supra*, Section 10.3 ("Comparison of Soil Data to LDNR 29-B Soil Standard"), and Section 12.3.1 ("Soil"). Section 12.3.1 proposes remediation of A1 South to a depth of 11 feet (larger area) and 10 feet (smaller area), and proposes remediation of A1 North to a depth of seven (7) feet.

[17] *Id.*, Sections 12.3 ("Remediation to Meet the Requirements of LDNR 29-B") & 12.3.1 ("Soil").

would transport the excavated soil offsite for disposal. Most of the estimated soil cleanup cost is for transportation and disposal.[18]

As indicated, the TD Plan proposes only remediating soil to applicable salt standards to a depth of three (3) feet below ground surface.[19] This is because, according to the TD experts, the roots (or root zone) for crops at Agri-South do not extend past a depth of three feet.[20] In other words, the TD Plan leaves soil that exceeds the applicable salt standards below three feet "as is".[21]

There is no depth limitation included in the 29-B salt standards. Salt parameter exceedances below three feet must meet the 29-B standards, unless there is an exception for good cause granted pursuant to LAC 43:XIX.319 which addresses LAC 43:XIX.313 soil conditions for salt parameters below three feet. Prior to the hearing, no exception pursuant to LAC 43:XIX.319

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[18] *See* AGS Plan, n. 3, *supra*, Section 10.4 ("Summary") & Sections 12.2.1("Soil") & 12.3.1 ("Soil). The costs per ton to excavate, load, haul, and dispose is estimated at $62.00 per ton. The estimated total cost for soil cleanup is $6,887,023. Most of this—84% ($52.00 of the $62.00 per ton) is for transportation and disposal. *See also* Arabie Testimony, 8/15/13, @ Vol. 8, pp. 170-71 & associated slide, **AGS 68**, PowerPoint slide 27.

[19] *See* TD Plan, n. 2, *supra*, Sections 4.3 ("Soil Remediation Goal"), 5.1 ("Discussion of and Comparison to 29-B Soil Standards") & 5.2.1 ("Identification of AOIs"). Read together, these provisions define TD's area of soil remediation as the "root zone", the zero to 3-foot depth interval. Further, Section 5.1 notes that the only "contaminated" soils that are salt-affected soils within the root zone are in a 0.49-acre area at the South AOI and a 0.38-acre area at the North AOI. According to Mr. Upthegrove, the lateral area was determined by looking at the zero to three-foot interval. *See* Upthegrove testimony, 8/8/13, @ Vol. 4, p. 136.

[20] *See* Upthegrove testimony, 8/8/13, @ Vol. 4, p. 179 & Vol. 5, pp. 22-23 ("The experts on our team don't believe ...the roots on crops at Agri-South and the surrounding area extend past the depth of three feet."); *see also* Daigle testimony, 8/9/13, @ Vol. 5, pp. 110, 152, 163 ("In our opinion, the definition of contamination is based on the intended use of the land which we believe goes no deeper than three feet.").

[21] Mr. Upthegrove testified that for elevated salts deeper than three (3) feet, TD sampled for chloride and for sodium by the Synthetic Precipitation Leaching Procedure ("SPLP") under RECAP, and concluded that there were no exceedances of the most conservative standard using this method. *See* Upthegrove testimony, 8/8/13, @ Vol. 4, p. 136. *See also* TD Plan, n. 2, *supra*, Section 3.1.1 ("Soil Investigation and Results") & Section 3.1.1.3 ("Analytical Results"), stating that "SPLP chloride and SPLP sodium collected by MP&A and HET have maximum values of 592 mg/L and 414 mg/L, respectively, and are below the applicable RECAP Standards."

was requested by Tensas Delta, and none was granted. Instead of costing out a plan which remediated salt-impacted soil below three feet, Tensas Delta relied upon the definition of "contamination" in LAC 43:XIX.301 contending that there was no contamination below three feet because the root zone only went down to three feet.[22] That is one of the reasons a pre-hearing ruling was issued finding the TD Plan not in compliance with LAC 43:XIX.611.F.1.

Mr. Upthegrove, who compiled the TD Plan, conceded that "there are commonly crop roots that go below a depth of five to six feet," but then said "that's not what I understand to be the case…on the Plug Road property."[23] Mr. Daigle, Tensas Delta's primary soil expert, offered a photograph of corn roots from corn at another location in Catahoula Parish, not this site, and testified that the solum for this particular soil was about twenty-seven inches, but also indicated the roots in the photograph may go down to thirty-five to forty inches. He indicated that he felt that "three feet was a comfortable zone" that would "cover the root zone plus have a cushion."[24]

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[22] On June 14, 2013, counsel for Tensas Delta sent a letter on the Section 611.F.1 issue. In that letter, counsel stated in pertinent part:

> The 29-B salt parameters, which are agronomy-based standards, were evaluated and are proposed to be addressed within the root zone of the soils for this site (0-3 feet). Not applying the specific numerical standards for salt parameters provided for in LAC 43:XIX.313.D below the root zone (greater than 3 feet) would have no adverse impact on the reasonably anticipated future use of the property and would not qualify as 'contamination' as that term is defined under section 301.

Letter of June 14, 2013 from Louis E. Buatt to Thomas E. Balhoff, p. 3. The letter is Attachment 1 to Tensas Delta's Post-Hearing Brief, referred to in n. 8, *supra*. Mr. Daigle, in his testimony to the panel, essentially said the same thing: "In our opinion, the definition of contamination is based on the intended use of the land which we believe to be no deeper than three feet." *See* Daigle testimony, 8/9/13, @ Vol. 5, p. 163. *See also* Daigle testimony, 8/9/13, @ Vol. 5, p. 107.

[23] *See* Upthegrove testimony, 8/8/13, @ Vol. 4, p. 232. The TD Plan, n. 2, supra, Section 2.2 ("Land Use"), states that "soybeans, corn, milo (grain sorghum), wheat and cotton" have all been grown on the property. *See* Upthegrove testimony, 8/8/13, @ Vol. 4, p. 244.

[24] *See* Daigle testimony, 8/9/13, @ Vol. 5, pp. 108-10 & associated slide, **TD DNR Exhibit 24**, PowerPoint slide 15; *see also* Daigle testimony, 8/9/13, @ Vol. 5, pp. 187-88.

Dr. Provin was Plug Road's primary soil expert. The thrust of his testimony was that the soil at this site, Sharkey clay with shrink/swell properties which causes cracks in the soil, slickensides, macropores (which fill with water quickly) and micropores (which he said are tiny tubes that don't fill with water readily),[25] makes the zone for plant-available water deeper than just the root depth of a particular crop. According to Dr. Provin, rooting depths of cotton will generally be three to five feet; sorghum and soybeans will be two to four feet, as shown on his slide 19, and corn shown with root depth of three to five feet on his slide.[26] He testified that the very small, deeper, hair-like roots are actually the roots that pick up the moisture and nutrients from the soil.[27] He described how these roots draw moisture from plant-available water located in micropores at distances of as much as three to four feet through capillary action. In the absence of regular rainfall, he testified that this additional water from these distances is needed. He described adverse effects that high salinity of plant-available water has on the plants, and indicated it could result in desiccation of the plant.[28]

Dr. Provin stated he would remove the entire soil down to at least ten feet, analyzing salinity in one-foot increments through a grid sampling system, which would allow soil to be put back in place if it was not contaminated.[29] In cross-examination, he did admit to earlier deposition

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[25] *See* Provin testimony, 8/13/13, @ Vol. 6, pp. 29-36, 38, 41-42.

[26] *Id.*, pp. 54-55, and associated slide, **AGS 49**, PowerPoint slide 19.

[27] *Id.*, pp. 59-60.

[28] *Id.*, pp. 59-66. *See also Id.*, p. 179 (Dr. Provin's response to Mr. Delmar: "We could expect a drawing of, at the bottom of the roots,...up to another four feet would be reasonable.").

[29] *Id.*, pp. 119-20.

testimony where he said he would excavate only to six to eight feet in depth to get to an EC of less than 2.[30] During panel questions, Mr. Snellgrove asked Dr. Provin:

> Q. ….[I]s there some depth from the surface that you would feel would not need to be disturbed in order to support the intended uses that were identified earlier on your PowerPoint, the crop growth?
>
> A. As we look at a number of publications that I believe have actually been submitted here, one of the API documents, they refer to *six foot as often the minimum level. I'm in that six-to-eight foot area*, unless we have an area that is hypersaline immediately below that.[31]

(Emphasis in italics added).

All of the evidence supports the need to remediate **this particular Sharkey clay salt-impacted soil** to a depth greater than the three feet. The Agency agrees with the testimony as to the characteristics of Sharkey clay soil, including the potential distance from crop roots to plant-available water, and finds that the most feasible plan for protection of the natural resources and environment must remediate the soil at the Plug Road property to a depth of eight (8) feet.[32] Whether remediation to a depth greater than eight feet may be required at some future time will depend on whether the shallow groundwater monitoring results, field inspections, and analytical results from soils indicate the elevated salt levels have failed to come down within limits after the initial remediation.

As far as the horizontal extent of soil remediation needed in the AOIs, the TD Plan proposed to remediate 0.49 acres at the South AOI and 0.38 acres at the North AOI. The AGS Plan

[30] *Id.*, p. 135.

[31] *Id.*, p. 172 (Dr. Provin's response to Mr. Snellgrove.).

[32] *Id.* The Agency has chosen the more conservative depth in Dr. Provin's response to Mr. Snellgrove, and believes that it is supported by all of the testimony concerning the properties of the Sharkey clay soil at the site, and the crops that have been grown, or foreseeably could be grown at the site.

proposed larger remediation areas, but totaling less than five acres. The AGS Plan would remediate 2.47 acres and 1.64 acres more at the South AOI and North AOI, respectively.[33] The difference may be, in part, related to depth of contamination. AES may have included acreage for remediation where below surface contamination migrated from the sources and remained below three feet, and would not have been included by Tensas Delta in its proposal since its proposal was only down to three feet. Also, the difference may in part be due to the fact that an EM31 meter was used by AES to gather conductivity data.[34] The EM31 meter is not as precise as actual analytical sampling. Where AES relied on a conductivity meter and not actual sampling, Tensas Delta (and AES) should conduct actual sampling to confirm the horizontal extent of the soil remediation.

Mr. Daigle, Tensas Delta's soil expert, explained the concept of the soil continuum, and he testified that the soil remediation should minimize, to the extent possible, any disturbance of the natural soil profile or continuum.[35] The Agency agrees with this objective. That is the reason that

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[33] The AGS Plan, n. 3, *supra*, Section 12.3.1 ("Soil"), indicates that the horizontal area that needs to be remediated at the South AOI are two areas of 2.47 acres and 0.49 acres, while the TD Plan, n. 2, *supra*, Section 5.1 ("Discussion of and Comparison to 29-B Soil Standards"), indicates that the total horizontal area that needs to be remediated for the two former pit areas, is 0.49 acres, or a difference between the two plans of 2.47 acres. *See also*, Upthegrove testimony, 8/8/13, @ Vol. 4, pp. 138, 143-44 (as to two pits at South AOI). The same figures for the North AOI are 2.02 acres (AGS), 0.38 (TD), and 1.64 acres (difference).

[34] The AGS Plan, n. 3, *supra*, Section 4.2.1 ("Terrain Conductivity Surveys"), states that AES used a "Geonics, Ltd., model EM-31 MK II terrain conductivity meter to collect conductivity data from investigated areas." Mr. Upthegrove stated that "within...about the upper most five meters, so about six [sic] feet below land surface....[w]e've seen that to be a good screening tool to just help determine where there's absence, presence, and relative concentration of salt....Mr. Arabie's team did that work. We weren't out there for the work, but we looked at that data...." Upthegrove testimony, 8/8/13, @ Vol. 4, pp. 126-27.

[35] *See* Daigle testimony, 8/9/13, @ Vol. 5, pp. 93, 114, 141-43, explaining that excavation interrupts the [physical soil] continuum and that "breaks it, severs it," but that the proposed gypsum, hay and nitrogen process is aimed at restoring "the chemical component" of the continuum, with the goal to "maintain the continuum while interrupting the continuum;" the proposed remedy seeks to "minimize the impact to the soil continuum." In connection with his testimony, Mr. Daigle's slide presentation, **TD DNR Exhibit 24**, PowerPoint slide 17, addressed this issue, stating that under the proposed method of chemical and mechanical treatment, "the soil is being...reconstructed as closely

Tensas Delta has proposed treating salt-impacted soil where the EC results >4 mmhos/cm and <10 mmhos/cm with gypsum, hay, and nitrogen fertilizer in one foot layers and **returning the treated layers to the same soil horizon**, on top of a gypsum layer and a six inch thick continuous capillary break. Both Tensas Delta experts, Mr. Daigle and by Mr. Upthegrove,[36] testified that they believe this method can be used effectively to remediate the soil at the Plug Road property. But, they were not able to confirm with any specific examples where this method had been used successfully in similar Sharkey clay soil structure, although there was some discussion about several fields, including a Jennings Field, and one panelist, Mr. Snellgrove, questioned Mr. Upthegrove about the similarity of the Jennings Field.[37]

Mr. Daigle testified that while the Sharkey clay soil is a heavy smectitic clay soil that is poorly drained and fairly impermeable, adding the gypsum will increase the soil porosity, and adding organic matter will increase pore volume even more.[38] He testified if the gypsum amendment doesn't work, they can always go back and excavate more, but under the Arabie plan, once you have "dug it all up" there is no going back.[39]

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as possible to its former layer orientation…[t]his will maintain, as closely as possible the 'soil continuum' that is so important to proper soil function." *See also* Provin testimony, 8/13/13, @ Vol. 6, pp. 167-68. Dr. Provin for Plug Road, while saying he would take the AES Plan over the TD Plan, acknowledged any soil backfilled should have "soil texture… somewhat similar" down to the bottom of the excavation.

[36] *See* Daigle testimony, 8/9/13, @ Vol. 5, pp. 110-14 & associated slide, **TD DNR Exhibit 24**, PowerPoint slide 16 ("Tensas Delta Soil Treatment Plan"). See also Upthegrove testimony, 8/8/13, @ Vol. 4, pp. 143-51 & associated slide **TD DNR Exhibit 19**, PowerPoint slide 30 ("Tensas Delta Soil Remedy").

[37] *See* Upthegrove testimony, 8/9/13, @ Vol. 5, pp. 49-52 (responding to Mr. Snellgrove's questions about Jennings field).

[38] *See* Daigle testimony, 8/9/13, @ Vol. 5, pp. 111-12.

[39] *Id.*, p. 144.

Dr. Provin, Plug Road's soil expert, testified he has used gypsum to remediate salt-affected soils numerous times, but he said it is necessary to look at this Sharkey clay soil differently than a silt loam soil, which he indicated was the soil type in the Jennings Field discussed above.[40] He testified about what he considered limitations to the chemical amendment process with gypsum proposed, and with the capillary break concept.[41] But, he admitted the "Arabie plan...pretty invasive," relying "on digging and hauling and then replacing that soil."[42] He did state, as noted earlier, he would remove the soil down to at least ten feet, analyzing salinity in one-foot increments through a grid sampling system, which would allow soil to be put back in place if it was not contaminated.[43]

It is unclear to the Agency from all of the testimony whether the Tensas Delta-proposed method of chemical amendment with gypsum, with a capillary break, will actually work in the Sharkey clay soil at this site. It is for this reason that the Agency considers the most feasible plan as including a site specific treatability study to determine the feasibility and effectiveness of the proposed gypsum treatment method in this Sharkey clay soil, and in reducing the EC levels to LAC 43:XIX.313D.3 criteria of 4 mmhos/cm or less throughout the vertical and horizontal salt - impacted soil areas at the Plug Road property to a depth of eight (8) feet. If the treatability study demonstrates that there will be compliance with the soil EC criteria of 4 mmhos/cm or less, then

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[40] *See* Provin testimony, 8/13/13, @ Vol. 6, pp., pp. 91, 121-22.

[41] *Id.*, pp. 92-108.

[42] *Id.*, pp. 110-11.

[43] *Id.*, pp. 119-120.

Tensas Delta can proceed to implement the treatment method. If not, then the most feasible plan should excavate and dispose of all of this soil to a depth of eight (8) feet.

Tensas Delta may elect to implement a site specific and comprehensive groundwater evaluation, to the Agency's satisfaction, that includes at a minimum all additional monitor well installations and data specified in the Agency's most feasible plan for groundwater evaluation and, based on the conclusions derived from the additional groundwater evaluation results, propose an alternative soil and groundwater remediation plan in accordance with LAC 43:XIX.Subpart 1.Chapter 3, including the exceptions provisions of LAC 43:XIX.319 and LAC 43:XIX.313, as necessary.

IV. GROUNDWATER EVALUATION

The information provided to LDNR/Agency before and during the hearing clearly established that groundwater below and surrounding the former exploration and production pit locations at the Plug Road property exceeds applicable salt parameters.[44] Tensas Delta's plan proposed monitoring the shallow groundwater, which admittedly exceeds RECAP standards,[45] and

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[44] *See* TD Plan, n. 2, *supra*, Executive Summary, no. 5: "Shallow groundwater within a limited area immediately beneath the former small pits exceeds RECAP standards as a result of historical E&P activities, but do not pose a threat to the water quality observed in the RRVA beneath the site due to the naturally poor water quality of the RRVA and an upward groundwater flow from the RRVA to the shallow zone." *See also* TD Plan, Section 4.2.1 ("LDEQ Groundwater Standards"), using SMCL of 250 mg/L ("ppm") as standard for chlorides and EPA drinking water advisory limit of 60 mg/L ("ppm") as standard for sodium; and TD Plan, Section 5.2.6.2 ("Comparison of Groundwater Data to RECAP Screening Standards"), Tables 3.7, 3.9 & 5.2 reporting shallow wells with chlorides as high as 12,700 ppm and sodium as high as 7,380 ppm. *See also* AGS Plan, n. 3, *supra*, Section 11.2 ("Recommendations for Corrective Action based on RECAP Findings"), using RECAP Standard for chlorides of 70 ppm (background chlorides according to AGS) and RECAP Standard for sodium of 60 ppm, Table reporting shallow groundwater with 13,100 ppm chlorides and 7,380 ppm sodium.

[45] *See* n. 44, *supra*.

proposed periodic reporting of the monitoring results to LDNR.[46] This "shallow groundwater strategy" required an exception for good cause pursuant to LAC 43:XIX.319 since it does not bring the groundwater to "background concentration" as set forth in LAC 43:XIX.303.C.[47] The plan did not include a separate plan complying with Statewide Order 29-B exclusive of §319 as required by LAC 43:XIX.611.F.1, and, did not include "sufficient proof that there is good cause to grant an exception or exceptions sought under §319" as required by LAC 43:XIX.611.F.2. This is the second reason that the TD Plan was deemed not in compliance with LAC 43:XIX.Subpart 1.Chapter 6.[48]

Plug Road's (AGS/AES) groundwater strategy included remediating the shallow groundwater **and** the RRVA, using a reverse osmosis groundwater recovery system estimated by Mr. Arabie at a cost in excess of $865 million, and would take fifty-six (56) years to complete.[49]

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[46] As to TD's provision for monitoring, *see* TD Plan, n. 2, *supra*, Section 4.4 ("Groundwater Assessment and Monitoring Goal"): "The objective of the groundwater assessment and monitoring program is to identify and monitor the water quality in the area of the shallow groundwater zone that appears to have been impaired by a historic produced water impact, while ensuring that the RRVA beneath the site is protected consistent with its current uses and reasonably-anticipated future uses and in consideration of its natural water quality." As discussed at the outset, Tensas Delta did **not** admit responsibility for elevated salt levels in the Red River Alluvial aquifer, but in fact proposed some monitoring in the RRVA.

[47] LAC 43:XIX.303.C provides in pertinent part: "Contamination of a groundwater aquifer or a USDW with E and P Waste is strictly prohibited." The February 25, 2011 LDNR/LDEQ Memorandum of Understanding ("MOU"), Item No. 2, indicates that LDNR and LDEQ consider Section 303.C to be a "background concentration" requirement for groundwater under 29-B, and that application of RECAP procedures for evaluation or remediation of groundwater at E&P sites is considered to be an "exception" to Statewide Order 29-B. While Mr. Stover categorized the shallow groundwater as Groundwater 3 classification, *see* Stover testimony, 8/6/13, @ Vol. 2, p. 191, he also testified that the shallow groundwater is in direct hydraulic communication with the alluvial aquifer. *See* Stover testimony, 8/5/13, @ Vol. 1, p. 187.

[48] *See* pages 7-8 of text, *supra*, as to the first reason that the plan was not in compliance.

[49] *See* AGS Plan, n. 3, *supra*, Section 12.2.2 ("Groundwater"), with cost of installation, maintenance, and reverse osmosis, estimated at $865,801,454. *See* Arabie testimony, 8/15/13, @ Vol. 8, p. 184 & associated slide, **AGS 68**, PowerPoint slide 48.

Most of the cost, ninety percent or more, is for transportation and offsite disposal.[50] At this time, particularly where the Agency does not have sufficient information about the alluvial aquifer and the source of the chlorides, as discussed below, the Agency considers this groundwater plan excessive, and not feasible.

There is evidence of elevated chloride levels in the RRVA beneath the Plug Road property,[51] but there it is not clear evidence as to whether the elevated chloride levels are being caused by former E&P operations, or are naturally occurring. Three witnesses (Mr. Stover, Dr. Reynolds, and Dr. Keuper) testified on behalf of Tensas Delta that the elevated salt in the alluvial aquifer was not from E&P operations, and two of those, Mr. Stover and Dr. Keuper, testified that the chlorides were naturally occurring and coming from the underlying Williamson Creek aquifer, but all of the evidence they offered was circumstantial and inconclusive. Mr. Stover, based principally on his review of historical information (geological articles, studies, and reports related to Catahoula Parish, or the surrounding region), concluded there was direct hydraulic contact between the alluvial aquifer and the underlying Williamson Creek aquifer, which he said was naturally salty.[52] Although he believed there was a sample taken from Williamson Creek which established this,[53] Mr. Bray, an expert hydrogeologist for Plug Road, disputed some of the interpretations and conclusions that Mr. Stover drew from the historical articles, studies and

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[50] *See* Arabie testimony, 8/15/13, @ Vol. 8, p. 222.

[51] The AGS Plan, n. 3, *supra*, Section 11.2 ("Recommendations for Corrective Action based on RECAP Findings"), reports chloride levels of 5680 ppm in the alluvial aquifer. The AES Alluvial Aquifer Chloride Map, *see* **TD DNR Exhibit 14**, PowerPoint slide 28, used by Mr. Stover during his testimony, shows elevated chloride levels as high as 5380 ppm, and generally in the 4000 to 5000 ppm range throughout the vicinity of the AOIs.

[52] *See* Stover testimony, 8/6/13, @ Vol. 2, pp. 182-83 & associated slide, **TD DNR Exhibit 14**, PowerPoint slides 52- 53.

[53] *See* Stover testimony, 8/5/13, @ Vol. 1, pp. 134-35, 146.

reports, notably, the interpretation that there is an incision from a side channel of an old river bed underlying Plug Road that results in hydraulic connection between the alluvial aquifer and Williamson Creek, and disputed that there was any sample of water which came from Williamson Creek beneath Plug Road. He provided a soil core during his testimony which suggested the water sample Mr. Stover relied on was really taken from the alluvial aquifer, not from Williamson Creek. He also testified that "all borings that have been installed have encountered clay...and there's not a hydraulic connection between the sand of the alluvial aquifer and the Williamson Creek."[54] Dr. Keuper, who testified on behalf of Tensas Delta that there was upward gradient in the alluvial aquifer which he said would prevent contamination from the shallow groundwater from moving downward into the alluvial aquifer, admitted that there have been no water samples of Williamson Creek taken:

> Q. Now just so the panel is clear, regarding this opinion that there are chlorides in the Williamson Creek aquifer that have migrated into the alluvial aquifer, neither you nor any of the oil company's other experts ever took any water samples from the Williamson Creek formation beneath the Plug Road property; right?
>
> A. Not from beneath the Plug Road property, that's correct.[55]

This means that there was no direct sampling evidence at the hearing that established Williamson Creek is salty beneath Plug Road, and thus no direct evidence that the salty conditions in the alluvial aquifer are coming from Williamson Creek below as opposed to from the contaminated soil and shallow groundwater above. The Agency does not feel that Dr. Reynolds' isotope analysis, relying as it did on only two alluvial aquiver water samples and only one "unimpacted" sample, selected in a way that they do not appear to have been based on any statistical or other

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[54] *See* Bray testimony, 8/14/13, @ Vol. 7, pp. 282-84.

[55] *See* Keufer testimony, 8/14/13, @ Vol. 7, p. 131.

methodology that would ensure that they were truly representative of what they purported to be, in relation to Wilcox formation water, is sufficient proof that the source of chlorides in the alluvial aquifer was something other than E&P operations. Simply put, the analysis did not appear to be based on representative, or on statistically sufficient, data.

The dispute as to alluvial aquifer groundwater is simple to understand. Tensas Delta claims that 1) Williamson Creek is salty, and 2) is hydraulically connected to the alluvial aquifer beneath Plug Road, so that 3) Williamson Creek is the source of the elevated salt in the alluvial aquifer. Plug Road disputes Tensas Delta's claim, and says that that there is a confining layer of clay in place beneath Plug Road that separates the two aquifers and prevents whatever is in the Williamson Creek aquifer from getting into the alluvial aquifer.

But neither side provided any direct evidence to support or refute No. 1, and **Tensas Delta did not present any direct evidence to support No. 2**, and **Plug Road's boring**, **B-14**, **evidence is not sufficient evidence to establish that there is a complete clay layer between the two aquifers beneath Plug Road**. In addition, on the collateral issue of leakage from plugged and abandoned wells, despite the testimony of Mr. Bazer and Dr. Warner on behalf of Tensas Delta, there is simply not enough direct evidence to decide whether one or more of the plugged and abandoned wells, (SN 159595) (T-125) & (SN 164189) (T-133), particularly the salt water disposal well, T-133, has leaked and caused any adverse salt impact to the surrounding soil and/or groundwater.

Based on all applicable information provided to the Agency before, during and after the hearing, it has been determined that conclusive, comprehensive sound and objective site specific lithology and aquifer information or data does not exist at this time to make a reasonable assessment of whether either of the parties' proposed groundwater strategies would be effective or even necessary.

Additional geologic, hydrogeologic, lithologic, shallow aquifer, Red River Alluvial aquifer and Williamson Creek aquifer site specific data is necessary for the Agency to complete its review and assessment of the vertical and horizontal extent of impact to groundwater resulting from past exploration and production activities at the Plug Road property.

The groundwater evaluation plan is set forth in detail in the Most Feasible Plan, including estimated cost, and is designed to provide Agency staff with additional information that has been determined to be necessary at this time to determine the source of elevated chlorides (naturally occurring or E&P Waste) in the Red River Alluvial aquifer and to consider and evaluate the feasibility of regulatory-appropriate groundwater remediation options that may be implemented in the shallow aquifer and, if necessary, the Red River Alluvial aquifer below the Plug Road property. It is anticipated that the information derived from installation and quarterly sampling of the wells included in this plan coupled with the previously installed wells at the Plug Road property will be beneficial in evaluating groundwater conditions around the former production well (SN 159595) (T-125) and salt water disposal well (SN 164189) (T-133) locations to determine if one or both well bores are contributing to the presence of elevated chlorides in the shallow or alluvial aquifer at the site.

V. <u>CONCLUSION</u>

In consideration of, and based on, all the evidence, the Agency's Most Feasible Plan is the most reasonable plan which addresses the admitted environmental damage to soil and shallow groundwater, and also addresses the alluvial aquifer issue, in conformity with the Louisiana Constitution, Article IX, Section 1 to protect the environment, public health, safety and welfare, and is in compliance with the specific relevant and applicable standards and regulations as mandated by La. R.S. 30:29.

James H. Welsh
Commissioner of Conservation

Date 10/3/2013

STATE OF LOUISIANA
DEPARTMENT OF NATURAL RESOURCES
OFFICE OF CONSERVATION

IN RE: **DOCKET NO. ENV-L-2013-02**

Agri-South, L.L.C., et al. v.
Exxon Mobil Corporation, et al.
Docket No. 24,132,
Seventh Judicial District Court,
Parish of Catahoula

EXHIBIT 1 TO WRITTEN REASONS
(PANELISTS AND THEIR BACKGROUNDS)

The seven panelists who served for the public hearing in the captioned case from August 5-16, 2013 are:

1. **Mr. Gary W. Snellgrove**. Mr. Snellgrove has a Bachelor of general studies from LSU in 1988, and an M.S. in environmental science from McNeese State University in 1993. His training at McNeese concentrated in environmental technology, environmental remediation, and environmental cleanups, and included courses in solid waste, hazardous waste, and groundwater issues. After working in the petrochemical industry in environmental matters for the next five years, including as a project manager for the Citgo Refinery in industrial hygiene and filtration services, he joined LDNR in 1998. He started as an environmental impact manager working with the injection and mining division in the E & P waste management program. In 2007, he became the Environmental Division Director at LDNR with responsibility for the legacy site remediation program and groundwater resources management. He is currently in that position today. He previously served on the LDNR panels for Public Hearings held pursuant to Act 312 in the Tensas Poppadoc (2009), Savoie (2012), and Avahoula Resources (2013) cases.

2. **Mr. Stephen Pennington**. Mr. Pennington has a B.S. in renewable natural resources from Texas A&M University in 1981. He worked in a variety of jobs that required technical training, including lab technician at Dow Chemical, quality assurance in the analytical chemistry lab at Ciba-Geigy, wetland delineations and endangered species surveys at HNTB Corporation, paralegal work on environmental cases for the Kean

Miller law firm, naturalist interpretative work for the Office of State Parks, and then, in 1999, he joined LDNR as a coastal resource scientist in the Coastal Management Group. In 2007, he transferred to LDNR's Office of Conservation to join the legacy group. In 2010/2011, his title became environmental impact manager, and he was involved with above ground issues, mainly soils and vegetation, but his duties also included looking at groundwater data to compare it to screening standards under RECAP. He reported directly to Mr. Gary Snellgrove. He is currently in that position today and continues to report directly to Mr. Snellgrove. He previously served on the LDNR panels for Public Hearings held pursuant to Act 312 in the Tensas Poppadoc (2009), Reese (2012), Savoie (2012), and Avahoula Resources (2013) cases.

3. **Mr. Christopher M. Delmar**. Mr. Delmar has a B.S. in geology from Louisiana Tech University in 2002, and attended LSU for two years in the Masters program for geology with specialization in hydrogeology. He completed all of the Masters work with the exception of completing his thesis. He joined LDEQ in 2005 as an Environmental Program Analyst, and then moved to an Environmental Scientist in the chemical accident prevention program. In 2008, he joined LDNR as a geologist working in the legacy group and groundwater resources group. He is currently in this position today. In connection with legacy work, he reports to Mr. Stephen Pennington. He previously served on the LDNR panels for Public Hearings held pursuant to Act 312 in the Savoie (2012) and Avahoula Resources (2013) cases.

4. **Ms. Sabrina Vutera**. Ms. Vutera received a B.S. in zoology from Southeastern Louisiana University in 1999. In January of 2000, she began her career as an Environmental Scientist at Louisiana Department of Environmental Quality in the Office of Environmental Compliance, Enforcement Division. She performed technical reviews of multi-media referrals for regulatory comprehensiveness and consistency to support violations and drafted appropriate enforcement actions for the following media: Solid Waste, Hazardous Waste, Underground Storage Tanks, Radiation, and Water Quality. She continued within the LDEQ for over thirteen years. In January of 2013, she joined the Louisiana Department of Natural Resources in the Office of Conservation as an Environmental Impact Specialist working in the legacy group. She is currently in this position today and reports directly to Mr. Stephen Pennington. She previously served on the LDNR panel for Public Hearing held pursuant to Act 312 in the Avahoula Resources (2013) case.

5. **Mr. Travis Williams**. Mr. Williams has a B.S. in geology from Western Kentucky University in 1999 and an M.S. in geology from the University of South Carolina in

2001. He worked as a hydrogeologist for the South Carolina Department of Health and Environmental Control, (SCDHEC) regulating the assessment and remediation of underground storage tank (UST) sites under a risk-based program. He then joined the Louisiana Department of Environmental Quality in 2003, as a geologist regulating the assessment and remediation of UST, solid, and hazardous waste facilities under RECAP as well as geological support for solid and hazardous waste permits. In 2007, he worked as a geologist in a private consulting firm in Grand Rapids, Michigan and in 2011 as a hazardous waste and safety specialist in the chemical and radiation safety sections at the University of Houston in Houston, Texas. Recently, Mr. Williams joined the Louisiana Department of Natural Resources and holds the title of Associate Scientist in the Environmental Division working on legacy sites and special projects, reporting directly to Mr. Gary Snellgrove. He previously served on the LDNR panel for Public Hearing held pursuant to Act 312 in the Avahoula Resources (2013) case.

6. **Mr. J. Brent Campbell, P.E.** Mr. Campbell has a B.S. in petroleum engineering from LSU in 1984. He joined Pipeline Division at LDNR as a staff engineer in 1984 and worked in that position until 1989 at which time he moved into the Engineering Division/Inspection and Enforcement Section at LDNR at the same level. His responsibilities in that section included addressing compliance issues at oil and gas facilities such as abandonment of wells and associated site restoration, closure of oilfield pits, remediation of onsite spills, and remediation of groundwater. In 1996, he became manager of the section and continued in that position until 2006. In 2006, he became the Director of Pipeline Division of Conservation until early 2013. In April of 2013, he became the director of the Engineering Regulatory Division at LDNR with responsibility over the Inspection and Enforcement Section, Oilfield Site Restoration Section, and the three District Offices. He is currently in that position today. He previously served on the LDNR panel for Public Hearing held pursuant to Act 312 in the Avahoula Resources (2013) case.

7. **Brandon Breaux.** Mr. Breaux is currently an Engineer Intern with the Office of Conservation. He graduated from LSU in December 2010 with a B.S. in biological engineering. He has been with Louisiana Department of Natural Resources since January 2011 working in the Environmental Division. He is primarily assisting in the regulatory oversight and groundwater resource management. Duties include implementation and enforcement of regulations under LAC56:I Chapters 1-7 for water well registration, construction, plugging and abandonment and database management. This case is Mr. Breaux's first service on an Act 312 panel.

Mr. Williams is employed by LDNR, but not within the "Office of Conservation." The other six panelists are employed by LDNR within the Office of Conservation.

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Docket No. 24,132,
Seventh Judicial District Court,
Parish of Catahoula

EXHIBIT 2 TO WRITTEN REASONS (EXPERT WITNESSES WHO TESTIFIED)

The expert witnesses who testified at the Agri-South Public Hearing held August 5-16, 2013:

Expert witnesses who testified on behalf of Tensas Delta:

1. **Mr. Stewart Stover**. He has a B.S. in geology and an M.S. in geosciences, both from University of Louisiana Monroe (formerly Northeast Louisiana). He is the principal hydrogeologist for Hydro-Environmental Technology located in Scott, Louisiana. He has been with HET for 23 years. He was tendered and accepted as an expert in areas of geology, hydrogeology, site groundwater investigation and remediation in accordance with 29-B and RECAP. 8/5/13, @ Vol.1, pp. 66-67, 70 and 73.

2. **Mr. Joseph Austin**. He has a B.S. in business from Trinity University in Texas. He is the president of Earth Measurement Corp. located in the Houston, Texas area, which is a company he formed in 1990. EMC specializes in near surface geophysical measurements. He was tendered and accepted as an expert in the interpretation of geophysical surveys and geophysical data interpretation data. 8/6/13, @ Vol. 2, pp. 218, 221, 227, 233-34.

3. **Dr. David Reynolds**. He has a B.S. in applied science (geological engineering) from the University of Waterloo, Ontario, Canada. He has an M.S. and a Ph.D. in civil/ environmental engineering from Queen's University, Kingston, Ontario, Canada. He works for Geosyntec Consultants located in Kingston, Ontario, Canada. He was tendered

as an expert in hydrogeology, geochemistry and stable isotopic analysis, but only accepted for hydrogeology and stable isotopic analysis. 8/7/13, @ Vol.3, pp. 91-92, 104, and 109.

4. **Mr. Donald Bazer**. He has a B.S. in petroleum engineering from LSU. He has 50 years experience in the upstream oil and gas industry, including with Amerada Hess. He has been a consulting engineer since 1990, and presently works as a consulting petroleum engineer through DOR Lease Service in Lafayette, Louisiana. He was tendered and accepted as an expert in the field of petroleum engineering. 8/7/13, @ Vol.3, pp. 212-14, 218 and 219.

5. **Mr. David Upthegrove**. He has a B.S. in geology from the University of Oklahoma, and postgraduate work in geology and hydrogeology from the University of Louisiana Lafayette, Georgia State University, and the University of New Orleans. He works for Michael Pisani & Associates, an environmental consulting firm, and is located in Sugarland, Texas. He was tendered and accepted as an expert in geologist, hydrogeology and site assessment. 8/8/15, @ Vol. 4, pp. 112-15.

6. **Mr. Jerry Daigle**. He has a B.S. in agronomy with an emphasis in soil science from LSU. He did graduate work toward his M.S. at LSU, and during that time, did agriculture research for two years at the LSU agriculture experiment station. He spent 38 years with the United States Department of Agriculture ("USDA"), and while there he was the state soil scientist for Louisiana for 17 years. He presently works as a private consultant for a company he started, Blue Frog Environmental, Soils & Wetland Services. He was tendered and accepted as an expert in the areas of soil science, soil investigation, soil interpretation, soil classification and soil remediation. 8/9/13, @ Vol. 5, pp. 64, 75, 81 and 87.

7. **Dr. Don Warner**. He has a B.S. and an M.S. in geological engineering from the Colorado School of Mines. He has a Ph.D. in engineering science with a major in geological engineering, geology, and civil engineering from the University of California at Berkley. He was on the faculty in geological engineering at University of Missouri at Rolla, and then was chairman of the department for 12 years, and then dean of the School of Mines and Metallurgy for another 12 years. After retiring from University of Missouri at Rolla, he now lives near Austin, Texas and works in private consulting. He was tendered and accepted as an expert in the field of geological engineering and an expert in injection well technology. 8/13/13, @ Vol. 6, pp. 182-84, 188 and 189.

8. **Dr. Bernie Kueper**. He has a B.S. in civil engineering from the University of Waterloo, and a Ph.D. in contaminant hydrogeology from the Department of Earth Sciences of the University of Waterloo. He is on the faculty of Queens University in Kingston, Ontario, Canada, and has been on the faculty there for 23 years. He teaches undergraduate and graduate courses in groundwater flow, solute transport and remediation of contaminants. He was tendered and accepted in the fields of hydrogeology, fate and transport, site characterization, groundwater flow and groundwater remediation. 8/14/13, @ Vol. 7, pp. 8-9, 19 and 20.

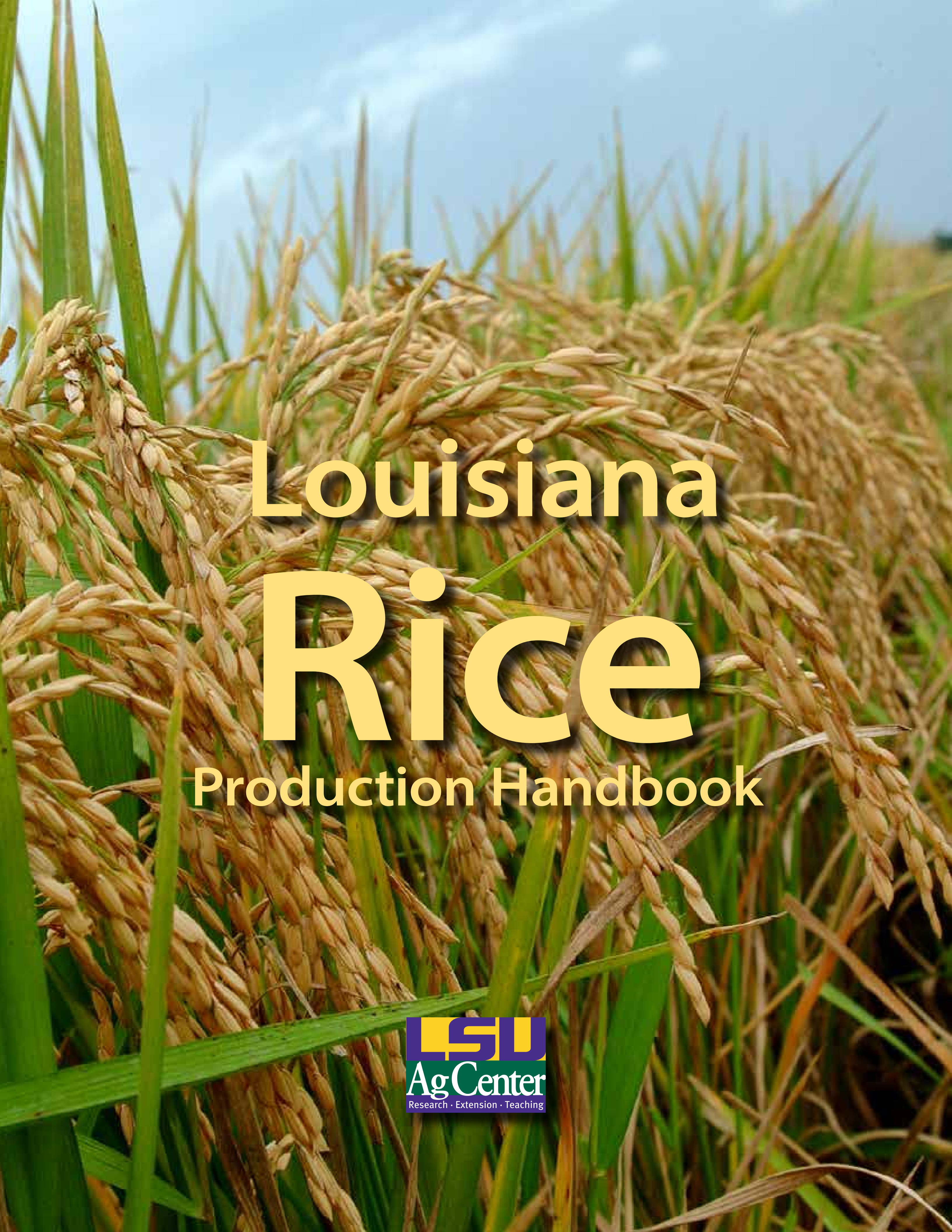
Expert witnesses who testified on behalf of Plug Road:

1. **Dr. Tony Provin**. He has a B.S. in agricultural science, with a sequence in agronomy, from Illinois State University. He has an M.S. in soil fertility from Iowa State University. He has a Ph.D. in soil chemistry from Purdue University. He is employed by Texas A&M Agri-Life Extension Services as a professor and soil chemist. He has run the public service soil science laboratory at Texas A&M for 17 years. He was tendered and accepted as an expert in soil science, agronomy, soil chemistry, soil fertility, fate and transport of materials within soil, plant development, and remediation of salt-affected soils. 8/13/13, @ Vol. 6, pp. 12-14, 20 and 22.

2. **Mr. Brent Bray**. He has a B.S. in geology from Virginia Tech. He has an M.S. in geology, with an interest in hydrogeology, from LSU. He is employed by Sigma Environmental Inc. in Covington, Louisiana. He is a geologist, with emphasis in hydrogeology, and has been in environmental consulting in this field for 25 years. He was tendered and accepted as a geologist with a specialty in hydrogeology, including site investigation, contamination of soil and groundwater by oilfield products, and remediation of property contaminated by oilfield waste. 8/14/13, @ Vol. 7, pp. 252-53, 262 and 264.

3. **Mr. Austin Arabie**. He has an M.S. in environmental science from McNeese State University in 1973. He has been involved in environmental cleanup operations in Louisiana since 1984. He has been the principal in his own environmental consulting firm located near Deridder, Louisiana since 1989. He was tendered and accepted as an environmental scientist with a specialty in soil and groundwater sciences, including contamination of soil and groundwater by oilfield products and remediation of property contaminated by oilfield waste. 8/15/13, @ Vol. 8, pp. 138-42, 144-45, 150.

ATTACHMENT 3



Louisiana Rice Production Handbook

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Louisiana Rice Production Handbook

Foreword

Rice is one of the world's most important cereal crops. Cereal crops are members of the grass family (*Gramineae* or *Poaceae*) grown for their edible starchy seeds. The term "cereal" is derived from the Greek goddess, Ceres or "giver of grain." Rice and wheat are two of the most important cereal crops and together make up the majority of the world's source of calories. They feed the world.

In the United States rice is grown on approximately three million acres in two distinct regions, California and several southern states; Arkansas, Louisiana, Mississippi, Missouri and Texas. A small amount is also grown in Florida and South Carolina. Rice has been grown in Louisiana for over 300 years and today is one of the most important crops grown here.

In 1987 the first Louisiana Rice Production Handbook was published with the intent of putting into one volume a comprehensive reference to all aspects of rice production in Louisiana. The handbook was revised in 1999 with extensive changes and again in 2009. The 2009 edition was so popular it became apparent supplies of printed copies would be exhausted well before the anticipated ten year revision anniversary would be reached. Rather than re-print that edition the authors decided to update it with new information, better and more photographs and the latest in research information. This edition retains the enduring information from the first, second and third editions, deletes dated product references, and adds the latest in rice production information. Many of the earlier references to crop protection chemicals and specific rice varieties have been eliminated to avoid early obsolescence. That information is available in the annually revised publication 2270, "Rice Varieties and Management Tips."

This publication is a product of the cumulative efforts of numerous scientists of the LSU Agricultural Center at the Rice Research Station in Crowley and from the main campus in Baton Rouge. All errors and omissions are the responsibility of the editor.

Edited by
Johnny Saichuk

Table of Contents

Chapter 1

General Agronomic Guidelines

Dustin Harrell and Johnny Saichuk

Site Selection and Land Forming

Rice is grown under flooded conditions; therefore, it is best produced on land that is nearly level. Level tracts of land minimize the number of water-retaining barriers or levees required per unit of area (Fig. 1-1). Some slope is required, however, to facilitate adequate drainage even though the practice of growing rice on "zero grade" or level fields has gained in popularity (Fig. 1-2). Generally, a slope of less than 1 percent is adequate for water management. Most of Louisiana's rice-growing areas are well-suited for rice production with a minimum of land forming. Recent innovations using laser systems have made precision leveled or graded fields physically and economically feasible.

Fig. 1-1. More slope requires more levees.

Precision grading a field to a slope of 0.2-foot or less difference in elevation between levees is important in rice production for several reasons: (1) it permits uniform flood depth, (2) it may eliminate a large number of levees, (3) it facilitates rapid irrigation and drainage, (4) it can lead to the use of straight, parallel levees that will increase machine efficiency, (5) it eliminates hills and potholes that may cause delay of flood and/or less than optimum weed control and (6) it reduces the total amount of water necessary for irrigation.

In the past, leveling land was done first by identifying the natural slope or contour in fields using standard surveying methods. Then, levees were constructed following contour lines with a 0.2-foot elevation interval. The development of laser-leveling equipment has drastically improved both accuracy and efficiency

Fig. 1-2. Zero grade field.

Fig. 1-3. Laser leveling.

of land forming (Fig. 1-3). A laser emitter is set up on a stationary platform. Tractor-drawn implements, ranging from a simple straight blade to massive dirt buckets, are equipped with laser receivers and a computer. The computer is programmed according to the needs of the grower and field. As the tractor travels over the field, the implement removes soil from the high areas and deposits it in low areas creating either a gradual slope or completely level field depending on the programming and intended farming practices. On silt loam soils with a distinct hard pan, the procedure may be done while the field is flooded and is termed water leveling (Fig. 1-4).

On soils with deep profiles, such as the heavy clay soils of Mississippi and Red River alluvium, drastic cuts are often made to land. Although this practice certainly facilitates water management, it often creates fertility or productivity problems. Some herbicides prohibit their use on recently leveled ground because of phytotoxicity to rice and/or ineffective weed control. Until the subsoil layers weather, production problems may occur. Recovery of these areas usually takes from two to several years, depending on severity of cut and soil properties.

Soils

Rice can be grown successfully on many different soil textures throughout Louisiana. Most rice is grown on the silt loam soils derived from either loess or old alluvium that predominate the southwestern region and, to a lesser extent, the Macon Ridge area

Fig. 1-4. Water leveling.

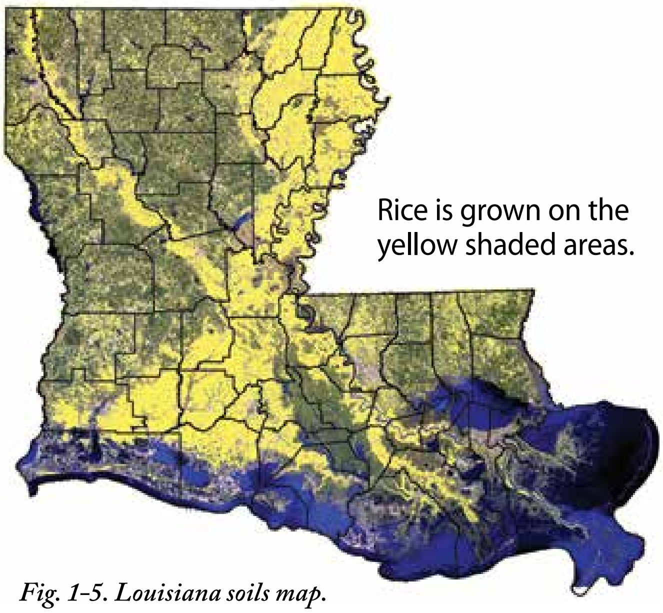


Fig. 1-5. Louisiana soils map.

of northeast Louisiana. The clay soils in the northeastern and central areas derived from more recent alluvial deposits are also well adapted to rice culture (Fig. 1-5). Deep, sandy soils are usually not suitable for rice production. The most important soil characteristic for lowland rice production is the presence of an impervious subsoil layer in the form of a fragipan, claypan or massive clay horizon that minimizes the percolation of irrigation water. Rice soils in Louisiana must be able to hold water in the paddies, which are, in essence, small ponds.

Experimentation with rice production under upland or nonflooded conditions in Louisiana has not been successful.

Water Requirements

The ability to achieve optimum water management is essential in attempting to maximize rice yields. The single most important management practice is the ability to flood and drain rice fields in a timely manner. In general, pumping capabilities are adequate if a field can be flushed in 2 to 4 days, flooded in 4 to 5 days and drained, dried and re-flooded in 2 weeks. This is much easier to accomplish on fields that have been uniformly leveled to a slope of no more than a 0.2-foot fall between levees.

Sloped fields take advantage of gravity to flood and drain the fields. Usually, the top paddy is flooded and water overflows into the next paddy and so on continuing to the bottom of the field. Draining is accomplished using the same openings in levees until the end of the season when levees are opened mechanically and the field is allowed to dry completely.

On zero grade fields, flooding and drainage are accomplished by constructing the field so that at least two sides are bordered by deep trenches. Most often, these are on three sides of the field. The surface of the field then is crossed (in two directions if necessary) with shallow ditches. Water is pumped into the border ditches until it spreads through the shallow surface ditches, eventually overflowing them and spreading throughout the field. Drainage in these fields is the reverse of the process.

The use of plastic (polyethylene) tubing, often called poly pipe, to flood multiple paddies simultaneously, has gained in popularity in some of the rice-growing regions of the state (Fig. 1-6). The plastic pipe is attached to the pump and water is pumped down one side of the field. Gates are installed in the tubing, or in some cases, the tubing is simply punctured to permit irrigation of all paddies at once. Size, shape and layout of the field all affect the economic efficiency of using this system.

Fig. 1-6. Using polypipe for irrigation.

Planting Dates

Some of the most important decisions that producers face are made prior to planting. Variety selection, planting date and appropriate seeding rate set the stage for the rest of the year, and good decisions here can translate into a better and more efficient harvest. Date-of-planting studies are conducted each year by LSU AgCenter researchers to adjust planting date recommendations. These studies include multiple varieties and planting dates and are designed to evaluate the optimum planting dates for new and popular varieties. Each year presents different environmental conditions, so there is not a single recommended date but rather a timeframe of about 1 month that is acceptable for planting.

LSU AgCenter recommendations for planting rice are from March 10 to April 15 in Southwest Louisiana and April 1 to May 5 in north Louisiana. On average, varieties planted during this time have the highest yield potential and milling quality and are generally easier to manage. Within this range is a lot of flexibility, and decisions should be based on specific field conditions. Average daily temperatures above 50 degrees F, calculated by adding the daily high and low temperatures and dividing by 2, are critical in obtaining an acceptable stand. Also, sufficient seeding rates and a well-prepared seedbed that promotes good seed-to-soil contact are necessary when planting at the early end of this range.

Planting early is desirable for high-yield potential, good milling quality and the option to produce a second crop (in south Louisiana), but extremely early planting can be detrimental in some cases. Slow emergence and reduced seedling vigor in cold conditions can lead to seedling disease and stand reductions. Depredation due to birds is more common in early-planted rice, so higher seeding rates are necessary to compensate for potential stand loss. Many herbicides are less effective under cooler conditions often associated with very early seeding dates. On the other end of the spectrum, late-planted rice can also be challenging. In addition to lower yield potential and milling quality, most insect and disease pests are more damaging in late-planted rice. Yield loss due to high temperatures and a lower chance for a successful second crop are common in late-planted rice.

Seeding Rates

Planting date should always be a major consideration when determining seeding rates because of the impact of temperature on stand establishment and the relationship between uniform stands and yield. A number of factors, such as low germination percentage, poor seedbed conditions, cold weather damage, seedling disease and bird depredation, can result in stand loss; therefore, sufficient seeding rates are critical to compensate for potential yield reductions. Rice is naturally a compensatory crop because of its ability to produce tillers, which provide flexibility in plant stand without affecting yield, but stands outside of the recommended range and uneven stands can be difficult and costly to manage.

LSU AgCenter recommendations for rice varieties range from 50 to 80 pounds of seed per acre for drill-seeding or dry broadcast seeding and 80 to 120 pounds of seed per acre for water-seeding rice to achieve a final plant stand of 10 to 15 plants per square foot. Typically, the lower end of these ranges should be used when conditions are ideal and the higher end when conditions are not conducive for good germination and plant establishment. Seeding rates for hybrid rice seed are much lower than for conventional varieties, and the hybrid seed representative should be consulted for recommendations. Stands that are too thin can result in increased weed competition, delayed maturity and decreased crop uniformity and quality. Conditions that justify a higher seeding rate include early planting, a poor seedbed, potential bird depredation, water-seeding and any other factor that can cause stand loss and impede plant establishment.

Excessively high seeding rates should be avoided as well, as they are more costly and can increase disease pressure and lodging. Ultimately, the goal is to determine how much seed should be planted to ensure a plant stand of 10 to 15 plants per square foot given the current field, seedbed and weather (soil moisture, temperature, forecast, etc.) conditions.

Conventional rice varieties, varieties and hybrids with Clearfield technology, and conventional hybrid rice vary widely in seed costs and reduced seeding rates are attractive economically requiring ideal planting conditions when reducing seeding rate or planting early. The money saved with a lower seeding rate or poor stand must be considered against potential additional expenses, such as replant costs, higher herbicide costs and other economic and agronomic factors.

Another important consideration is that seed size affects the recommended seeding rates in pounds per acre. For rice varieties, a final stand of 10 to 15 plants per square foot is optimal. In typical conditions, about 50 percent of planted seed produces a grain-bearing plant so a target seeding rate of 20 to 30 seeds per square foot is suggested to reach 10 to 15 plants per square foot. Seed size, and thus number of seeds per pound, varies among varieties, so a target seeding rate of 10 to 15 plants per square foot might require a different total seed weight per acre. For example, a medium-grain variety and a long-grain variety have 16,839 and 19,660 seeds per pound, respectively. Thus, a seeding rate for the medium-grain variety at 30 seeds per square foot would require 78 pounds of seeds per acre. The same seeding rate for the long-grain variety would require only 66 pounds to have the same number of seeds per acre.

Seeding rates of hybrid rice varieties are much lower than conventional rice varieties. Producers should consult the hybrid seed representative for guidelines and recommended seeding rates.

When water-seeding or dry broadcasting, 40 to 60 seeds per square foot will be required to obtain a satisfactory stand. When drill seeding, 30 to 40 seeds per square foot will be required. Within each category is a range of seeding rates to allow for some adjustment. The higher seeding rates should be used when planting under less than optimal conditions. Circumstances when the higher seeding rate should be used are as follows:

- When planting early in the season when the potential for unfavorably cool growing conditions exists. Cool conditions will favor water mold (seedling disease) in water-seeded rice, which can reduce stands. Varieties also differ in tolerance to cool growing conditions in the seedling stage.
- Where seed depredation by blackbirds is potentially high.

Fig. 1-7. Drilling seed into stale seedbed.

- Where seedbed preparation is difficult and a less than optimal seedbed is prepared.
- If the seed source has a low germination percentage. Certified seed with high germination percentage should always be used, if possible.
- When water seeding into stale or no-till seedbeds with excessive vegetation.
- If any other factor (slow flushing capability, saltwater problems, etc.) exists that may cause stand establishment problems.
- If dry or nontreated seed are used in a water-seeded system. Water-seeding research has shown that the best plant populations are obtained when planting presprouted, fungicide-treated seed. Presprouted, nontreated and dry fungicide-treated seed produce somewhat lower plant populations. Dry, nontreated seed produce the lowest plant populations.

Dry Seeding

Fertilization Timing and Water Management

Dry seeding is the predominant seeding method used in the north Louisiana rice-growing areas. Dry seeding normally performs well on soils where a well-prepared seedbed is practical and/or red rice is not a severe problem. Rice can be dry seeded using a grain drill or by broadcasting (Fig. 1-7).

When rice is drill-seeded, a well-prepared, weed-free seedbed is advantageous. A well-prepared seedbed will facilitate uniform seeding depth, which is important in establishing a uniform stand. Seeding depth is important with all varieties. It is especially critical with semidwarf varieties because these varieties are inherently slower in development during the seedling stage, and the mesocotyl length is shorter than conventional-height varieties. Therefore, semidwarf varieties should be seeded no deeper than 1 inch to maximize uniform stand establishment. Conventional-height varieties may be planted somewhat deeper, but seeding depths greater than 2 inches should be avoided with any variety.

Where soil moisture is adequate, a flush, or surface irrigation, following seeding may not be necessary. When soil moisture is insufficient and rainfall is not imminent, the field should be flushed within 4 days of seeding to ensure uniform seedling emergence. Therefore, levees should be constructed and butted at or soon after seeding.

Rice can be broadcast on a dry seedbed using either ground or aerial equipment. Seed should be covered using a harrow or similar implement. Uniformity of seeding depth is much more difficult to obtain when dry broadcasting. As with drill seeding, an immediate flush may facilitate uniform seedling emergence.

Fertilization timing and water management are similar for both drill-seeded and dry broadcast-seeded rice. Phosphorus (P), potassium (K) and micronutrient fertilizers should be applied preplant and incorporated based on soil test results. The addition of 15 to 20 pounds of preplant nitrogen (N) is generally recommended to ensure against N deficiency in seedling rice. Application of large amounts of preplant N should be avoided in a dry-seeded system since wetting and drying cycles before the permanent flood is established can lead to the loss of much of this N.

The majority of the N fertilizer should be applied to a dry soil surface within 3 days prior to permanently flooding the field. The remainder of the N requirement should be applied midseason. In some cases, all of the N fertilizer can be applied ahead of the permanent flood if the precise N requirement for a field is known and if the permanent flood can be maintained throughout the season. If a field must be drained, however, for any unforeseen reason such as water weevil larva control or straighthead, appreciable amounts of N can be lost requiring reapplication of N. When the required N fertilizer rate is not known or the field will be drained before harvest for any reason, apply 60 to 70 percent of the estimated N fertilizer requirement prior to flood establishment. Additional N fertilizer should be applied at midseason at the beginning of reproductive growth between panicle initiation [(PI), green ring (Fig. 4-10), or beginning internode elongation (IE)] and panicle differentiation (PD) (1/2 inch IE) (Fig. 4-11).

Large amounts of N fertilizer should not be applied into the floodwater on seedling rice because it is subject to loss. With this system, the permanent flood should be established as soon as possible without submerging the rice plants. This will normally be at the 4- to 5-leaf rice stage in fairly level fields. Delaying permanent flood with the intention of reducing irrigation costs may increase other production costs, reduce yields and decrease profits. Additional information on fertilizer timing in relation to water management can be found in the Soils, Plant Nutrition and Fertilization section.

Water Seeding

Fertilizer Timing and Water Management

Water seeding was once the predominant method of rice seeding used in Louisiana. It is still widely used in Southwest Louisiana and, to a lesser extent, in the northern portion of the state.

The use of a water-seeded system can provide an excellent cultural method for red rice suppression, which is the primary reason for the popularity of water seeding in Southwest Louisiana. Rice producers who raise crawfish in rice fields use water seeding because this planting method is easily adapted to rice-crawfish rotations. Other producers have adopted water seeding as a matter of custom, convenience or both. Water seeding is also an alternative planting method when excessive rainfall prevents dry seeding.

Seedbed preparation is somewhat different when water seeding is used compared with dry seeding. With water seeding, the seedbed is left in a rougher condition than for dry seeding. This is accomplished by preparing a seedbed consisting primarily of large clods (approximately baseball-size), which is often easier to attain with heavy-textured soils. A flood is established as soon as possible following tillage, and rice is seeded within 3 to 4 days. This will reduce potential weed problems and provide a more favorable oxygen situation at the soil/water interface. Low oxygen levels are often a problem where floodwater is held for a long time before seeding.

A preferable alternative to a rough seedbed is preparation of a smooth seedbed similar to that for drill

Fig. 1-8. Aircraft sowing seed.

seeding. Following smoothing, the seedbed is firmed with a grooving implement, resulting in a seedbed with grooves (1 to 2 inches deep) on 7- to 10-inch spacings. In some situations, a field cultivator can achieve the desired grooves. Some producers have constructed tools specifically for the purpose of establishing grooves, and these tools are based on similar tools used in California and on Louisiana ingenuity.

A rough seedbed will minimize seed drift following seeding and facilitate seedling anchorage and rapid seedling development. Seed and seedling drift is often quite severe, especially in large cuts common in precision-leveled fields. The large clods or shallow grooves provide a niche into which the seed can fall and provide some protection from wave action in a flooded field.

Fig. 1-9. Loading aircraft with seed.

Fig. 1-10. Presprouted seeds.

Dragging a field while it is flooded should be avoided before seeding because dragging: (1) leaves an extremely slick seedbed, which will compound problems with seed drift; (2) increases the severity of crusting and curling of the surface during the initial drain; (3) may displace and unevenly distribute incorporated fertilizers and herbicides; and (4) increases soil loss during the initial drain.

Water seeding is by necessity accomplished with aircraft using either dry or presprouted seed (Fig. 1-9). Presprouted seed offers the advantages of higher seed weight and initiation of germination because the seed has already imbibed water (Fig. 1-10). Presprouting is accomplished by soaking seed for 24 to 36 hours followed by draining for 24 to 36 hours prior to seeding (Fig. 1-11) These periods may need to be extended under cool conditions. A disadvantage to presprouting is that seed must be planted shortly after presprouting or deterioration will occur. Water management of water-seeded rice after seeding may be categorized as delayed flood, pinpoint flood or continuous flood.

Fig. 1-11. Soaking seeds.

Delayed-flood System

In a delayed-flood system, fields are drained after water seeding for an extended period (usually 3 to 4 weeks) before the permanent flood is applied. This system is normally used in fields where red rice is not a problem because the delayed flood system provides no red rice suppression. Fertilizer application timings and water management after the initial drain are similar to those in dry-seeded systems.

Pinpoint Flood System

The most common water-seeding method is the pinpoint flood system. After seeding with presprouted seed, the field is drained briefly. The initial drain period is only long enough to allow the radicle to penetrate the soil (peg down) and anchor the seedling (Fig. 1-12). A 3- to 5-day drain period is sufficient under normal conditions. The field then is permanently flooded until rice nears maturity (an exception is midseason drainage to alleviate straighthead). In this system, rice seedlings emerge through the floodwater, and seedlings must be above the water surface by at least the 4-leaf rice stage. Before this stage, seedlings normally have sufficient stored food and available oxygen to survive. Atmospheric oxygen and other gases are then necessary for the plant to grow and develop. The pinpoint flood system is an excellent means of suppressing red rice emerging from seeds in the soil because oxygen necessary for red rice germination is not available as long as the field is maintained in a flooded (or saturated) condition.

Continuous Flood System

Use of a continuous flood system is limited in Louisiana. Although similar to the pinpoint flood system, the field is never drained after seeding. Of the three water-seeded systems, a continuous flood system is normally best for red rice suppression, but rice stand establishment is most difficult. Even the most vigorous variety may have problems becoming established under this system.

Fertilization timing is the same for both the pinpoint and continuous flood systems. Phosphorus (P), potassium (K), sulfur (S) and zinc (Zn) fertilizers are

Fig. 1-12. Emerged seedlings ready for pinpoint flood.

applied preplant incorporated as in the dry-seeded system. Once the field is flooded, the soil should not be allowed to dry.

If the N requirement of a particular field is known, all N fertilizer should be incorporated prior to flooding and seeding. Otherwise, one-half to two-thirds of the estimated N fertilizer requirement should be incorporated prior to flooding and seeding or during the brief drain period in a pinpoint flood system. Additional N fertilizer can be applied at midseason at the beginning of reproductive growth between PI and PD. More information on fertilizer timing in relation to water management is in the Soils, Plant Nutrition, and Fertilization section.

Ratoon (Second or Stubble) Crop Production in Rice

The climatic conditions of Southwest Louisiana and the earliness of commonly grown rice varieties combine to create an opportunity for ratoon, or second/stubble, crop production. Ratooning is the practice of harvesting grain from tillers originating from the stubble of a previously harvested crop (main crop).

Weather during the fall will normally dictate the success of ratoon rice production. In Southwest Louisiana where rice is ratooned, the growing season prior to the onset of unfavorable temperatures is not long enough in every year to allow maturation of the ratoon grain. A decline in temperature and day length as the ratoon crop is developing could produce negative impacts on pollination, grain filling, ratoon rice yield and milling quality. Furthermore, the months of September and October, when ratoon rice is developing, are also the months when the production area is most susceptible to tropical weather systems.

Mild temperatures will speed ratoon maturity and prevent excessive sterility (or blanking) associated with low temperatures at flowering. Average daily high and low temperatures used in DD-50-based predictions are just as important in the development of ratoon rice as it is in the main crop. Later-than-normal first-frost dates will aid ratoon rice production, especially when the main crop is harvested later than August 15. The main crop should be harvested by August 15 to ensure adequate time for ratoon rice to develop. In years with an abnormally mild fall and a late first frost, ratoon rice can be produced when the main crop is harvested as late as the first week of September, but this is the exception rather than the rule.

While cooperation from the weather is essential for ratoon rice production, cultural practices play a critical role in maximizing ratoon rice yields. Cultural practices used in the main crop can have a major impact on ratoon rice production. Every management decision in the main crop will in some way impact the ratoon crop. Planting date, fertilization, and weed, disease and insect management in the main crop will all influence ratoon rice development and yield. Excessive nitrogen fertilizer applied to the main crop can delay regrowth of ratoon rice; therefore, overfertilization should be avoided even with a lodging-resistant variety. Severe disease pressure in the main crop may cause death of tillers and prevent regrowth from these plants, which will reduce ratoon rice production. Therefore, a foliar fungicide applied to the main crop can be beneficial to the ratoon crop.

Conditions at main-crop harvest will influence whether a ratoon harvest should be attempted. If the main crop is harvested under muddy conditions and the field is excessively rutted, ratoon rice production will be difficult and is not recommended. Excessive red rice in the main crop will also limit ratoon rice yield and quality. Where red rice is severe, ratoon rice production should be avoided and efforts should be concentrated on encouraging germination of red rice seed followed by destroying the seedlings with fall tillage, which may decrease red rice populations in successive crops.

An application of N fertilizer is necessary for high ratoon rice yields. Nitrogen fertilizer applications should be made to a dry soil surface and a shallow flood established immediately after harvest. This procedure will facilitate rapid regrowth and efficient use of applied N fertilizer. Recent studies with N fertilization rates in the ratoon crop indicate that a rate of 75 to 90 pounds of N per acre is sufficient for most commonly used rice varieties when first crop is harvested before August 15. Consult the annual LSU AgCenter publication 2270, "Rice Varieties and Management Tips," when selecting varieties with the intention of producing ratoon rice.

The second (ratoon) rice crop has become an integral part of commercial rice production in Southwest Louisiana. The ratoon crop will generally yield approximately one-third of that realized in the main crop. Although, ratoon yields are much less than that of the first crop, there is a definite economical advantage of growing the ratoon crop. It is economically productive because the input costs for producing the ratoon crop are kept at a minimal. Generally, the only costs associated with grow a ratoon crop are nitrogen (N) fertilizer, irrigation, harvesting and grain drying. While growing a ratoon crop is economically favorable to a producer, having a successful ratoon crop is not guaranteed every year. Although, traditional weather patterns in the southern rice growing region give us the opportunity to grow a ratoon crop, it is often weather that dictates the ultimate success of the endeavor. We cannot control the weather; however, there are several management strategies and decisions that we can use to improve our probability of success.

The first management decision begins before the main crop is even planted and that is to select an early maturing rice variety with a high ratoon potential. The second management decision is truly the "go" or "no-go" decision on attempting a ratoon crop. This decision should be made with information gathered from the main crop including an evaluation of disease pressure prior to harvest, the stubble conditions after harvesting and the date of harvest. Harvesting the first crop prior to August 15 will generally give the ratoon crop enough days of warm weather to grow a ratoon crop. There have been many seasons in the past when a main crop harvested after August 15 produced excellent ratoon yields; however, these were in years with mild fall temperatures and late first frosts. Unfortunately, there is no way of determining if this year will be one of those years. The earlier the main crop is harvested the better the probability of success with the ratoon crop. We must also remember that all management practices that we apply towards the main crop will have a bearing on the ratoon crop. For example, less than optimum weed and disease control will not only reduce yield in the main crop but will also be detrimental to the ratoon crop. A clean first crop will improve second crop yield potential. Another example would be harvesting a main crop in muddy soil conditions. This will certainly lead to increased rutting of the field and reduced ratoon yields in the rutted areas. There are even times when we may want to make the decision not to grow a ratoon crop at all. For example, high disease pressure will almost certainly spell disaster in the ratoon crop. You also might want to consider not growing a ratoon crop in fields with a heavy infestation of red rice. Take the measures to control the red rice problem now before it becomes more of a problem in future crops.

The final major decision is to determine whether or not to use a stubble management practice. Stubble management practices, such as harvesting at a lower than normal harvest height, reducing the stubble height by post-harvest flail mowing or bush hogging to around 8 inches, and rolling the stubble have all shown a yield benefit in studies conducted at the Rice Research Station in most years. The yield benefit can be up to several barrels per acre in some years. However, both harvesting the main crop at a lower than normal platform height, flail mowing, bush hogging, and rolling the stubble will delay the maturity of the ratoon crop approximately 2 weeks. So, if the main crop is harvested at a later than optimum date, further delaying the ratoon maturity by using one of these stubble management practices may not be the best decision. Interest in using a fungicide application in the ratoon crop has gained interest over the past several years. In a recent study at the Rice Station, application of a fungicide 4 weeks after harvest (coinciding with the first ratoon panicle emergence) did not reduce Cercospora incidence in the ratoon crop. On the other hand, lowering the ratoon stubble height by either flail mowing, bush hogging, or harvesting lower did reduce Cercospora incidence.

The next true management decision is when and how much N fertilizer to use. Our past ratoon N studies have shown that 90 pounds of N applied on a dry soil just after the main crop is harvested and immediately followed by a very shallow flood is the best management strategy in almost every study across all varieties and hybrids. If you make a decision to attempt a ratoon crop when the main crop was harvested after August 15, you will need to reduce the N rate. This will reduce the time to maturity of the ratoon crop and also reduce your investment in the ratoon crop. Nitrogen fertilizer should not be applied to the ratoon crop if the first crop is harvested after September 1.

Conservation Tillage Management

Enhancement of soil physical, chemical and biological properties is one of the major goals of sustainable agricultural production. Tillage practices are one way to impact soil properties and crop yields, hopefully with positive effects. Improvement of soil physical, chemical and biological properties is a technical factor. Tillage practices, however, are also directed by economic factors such as production costs, a producer's economic situation, commodity prices and credit availability. Therefore, a balance must be discovered that allows a producer to use sustainable production practices at economical levels.

Most rice in the United States is grown using conventional tillage; however, conservation tillage has gained acceptance in many rice-growing areas. No-till and reduced-tillage systems, such as fall- and spring-stale seedbeds, have been shown to significantly improve the quality of floodwater being removed from rice fields by reducing sediment losses. Problems, however, are associated with producing rice in this manner. Previous research conducted at the LSU AgCenter Rice Research Station since 1987 has addressed issues related to varieties not adapted to conservation tillage systems and yield reductions related to numerous factors involving conservation tillage. This research has firmly established the advantages and disadvantages of reduced-tillage rice production, and it has identified stand establishment and early-season plant density as critical components of managing a reduced-tillage rice production system.

Preplant and/or early season vegetation management are vital elements in reduced-tillage rice production systems. By minimizing the amount of preplant vegetation present in the seedbed, competition between the vegetation and the establishing rice crop is reduced. Additionally, plant residue can increase immobilization and volatilization of N fertilizer applied during the seedling rice stage, so proper management of preplant and early season vegetation also may reduce the amount of N fertilizer lost due to immobilization and volatilization.

The following information on conservation tillage in rice is based in part on specific research results obtained from reduced tillage rice research studies. Some information is generalized based on observations from these studies and not necessarily scientific measurements.

The basic components of these alternative tillage practices are summarized emphasizing advantages and disadvantages. This information is intended as general guidelines, but it may not be applicable to every situation. Three alternative methods of seedbed preparation have been compared with conventionally prepared seedbeds in both water- and drill-seeded cultural systems. These methods are defined as follows:

Spring Stale Seedbed

Seedbeds are prepared 3 to 6 weeks prior to planting. Depending on temperature and rainfall, vegetation that emerges prior to planting is usually small and easily controlled with herbicides. Most producers find little cultural advantage with spring stale seedbed compared with spring seedbed preparation at the normal time under a conventional tillage system. The spring stale seedbed system, however, offers one important benefit; during dry springs, seedbeds can be worked earlier in the year and prepared for planting, which improves the likelihood of timely planting. Time, money and labor are conserved by controlling preplant vegetation with a burndown herbicide rather than waiting for the seedbed to dry for mechanical preparation if excessive rainfall occurs prior to planting.

Fall Stale Seedbed

Seedbeds are completely prepared in the fall prior to rice planting in the spring. Vegetation that emerges during the winter months is usually uniform, 8 to 10 inches in height and consists of winter annual grasses, clovers, vetches and other broadleaf weed species. The fall stale seedbed system is the most popular reduced tillage practice in Southwest Louisiana. Better drying conditions and favorable weather in the fall allow more opportunity for field preparation.

No-till

Rice is planted directly into the residue of a previously harvested crop or native vegetation. In Southwest Louisiana, soybean is the typical rotational crop. Cotton and soybean are options in north Louisiana. Preplant vegetation is usually not uniform in size and usually consists of larger, woody winter weeds that create problems when controlling preplant vegetation (Fig. 1-13). Rice establishment practices used in conservation tillage systems are described below.

Preplant vegetation control. Several herbicides are labeled for preplant burndown applications in rice. The herbicide label should be consulted for application rate and weed control spectrum. Application rate depends on type and size of weeds present, and herbicides should be applied according to label directions. Some rice is planted in a no-till system without termination of preplant vegetation, which is possible if weed growth is minimal and species include winter annuals that will eventually die in the spring or be killed by flooding. Significant yield reductions have occurred in studies where preplant vegetation was excessive and a burndown herbicide was not used. Choosing not to apply a burndown chemical is risky, and weed identification is critical.

Time of application in relation to planting. Best results in most burndown research have occurred with a 7- to 10-day preplant herbicide application timing. These results are especially true when residual herbicides are tank-mixed with burndown herbicides. Longer intervals between burndown and planting reduce the effectiveness of residual weed control in the planted rice crop. Plant back restrictions also exist for a number of burndown herbicides, and these restrictions for rice vary dramatically depending on the choice of burndown herbicide. Burndown herbicides must be applied according to label directions. See the section on Weed Control for more details on burndown herbicide materials and timing.

Planting practices. Presprouting seed when using a water-seeded system will speed stand establishment and minimize seedling problems associated with poor floodwater quality, low oxygen, seedling diseases and

Fig. 1-13. Drilling seed into standing vegetation.

potential seed midge. Seed-to-soil contact is important and is a function of the amount of vegetation and, to some extent, the type of vegetation. When drill seeding, it is important to use planting equipment that places seed at a uniform depth and closes the seed furrow to conserve moisture. On some soils, no-till equipment may not be required. High-quality, conventional grain drills perform well on well-prepared seedbeds. Heavy, no-till equipment is desirable where vegetation is excessive and seedbeds are compacted.

Water management. Inadequate stand establishment is a common problem in water-seeded, no-till rice, especially in a pinpoint flood system. Delaying permanent flood establishment for 2 to 3 weeks after water seeding and initial draining will improve stand establishment in some situations. Adequate moisture, however, must be available through rainfall or irrigation in delayed flood systems. Excessive drying of the seedbed during rooting also can cause stand reductions. Delayed flooding is not a desirable management practice when red rice is a problem, and control or suppression of red rice will be significantly lower when delayed flooding is practiced. Red rice suppression using water seeding is less consistent under conservation tillage compared with conventional tillage systems.

Stand establishment difficulties encountered when drill seeding are often associated with inadequate moisture. If moisture is inadequate at planting, the field should be flushed to encourage uniform emergence and stand establishment. Gibberellic acid seed treatment also may enhance emergence of some varieties. In water-seeded systems, seed-to-soil contact is often poor. Consequently, frequent flushing in delayed flood systems may be required. In a pinpoint flood system, draining a field multiple times may be required to encourage rooting.

Variety selection. Variety selection when using a no-till system is important. Good seedling vigor, tillering ability and yield potential are important characteristics. Under ideal conditions, any recommended commercial variety could be considered. Research supports the fact that no-till and weedy stale seedbeds are not ideal situations, and varieties that possess the characteristics listed above perform most consistently under conservation tillage systems. Seedling vigor in some semidwarf varieties is lower than in tall varieties, often causing stand establishment problems in no-till seedbeds, especially if water seeded. This problem may result in lower yields. Taller varieties or those that possess good seedling vigor have performed best under conservation tillage systems.

Fertilizer management. Plant nutrients can be surface applied in a no-till system. In stale seedbed systems, phosphorus (P) and potassium (K) can be incorporated at the time of land preparation or surface applied in the spring. Nitrogen management in the spring rice crop is much easier when P and K are applied in the fall. Fertilizer efficiency, however, is much higher when spring-applied compared with fall applications, especially for K. In a no-till system where scumming may be a problem, P and K should be applied after rice stand establishment but before the 5-leaf rice stage. These nutrients can be applied into standing floodwater or before permanent flooding.

When not to no-till. Excessive vegetation, hard-to-control weeds, rutted fields, unlevel fields and fields where red rice is a problem are situations where a producer should consider conventional tillage practices. Heavy vegetation reduces seed-to-soil contact and increases problems establishing adequate stand. Weeds not controlled before planting will cause significant problems after planting. Rutted and unlevel fields impact both flooding and draining of rice fields.

Chapter 2

Rice Varieties and Variety Improvement

Steve Linscombe, James Oard and Larry White

Development of superior rice varieties has been an important tool for improving rice production in Louisiana and in the United States. Release of improved varieties by public breeding programs in Louisiana, Texas, Arkansas, Mississippi and California, in conjunction with advancements in rice production technology, has provided a continuous increase in rice production and quality. Considerable genetic potential exists to improve on current rice varieties, and rice breeding efforts should continue to help increase rice yield and profitability in Louisiana.

Rice Varietal Improvement Program

In the early days, Louisiana rice production depended on varietal introductions by individuals. In 1909, the first rice breeding program in the United States was initiated when the Rice Research (Experiment) Station was established at Crowley. The rice breeding activities there were under the direction of USDA scientists from the inception of the program until the Louisiana Agricultural Experiment Station (LAES) assumed responsibility for the program in 1981. The Rice Research Station has a long history of developing new varieties that benefit the Louisiana rice industry. Additional research projects were added over time, but variety development has always been a major focus of the station's research activities. Since its inception, the program has formally released 49 improved rice varieties (Appendix Table 1).

Variety development efforts require a great deal of time, money, hard work and travel by those involved, specialized field and laboratory equipment, and a high level of cooperation with producers and other research personnel. The first step in the development of a new variety is to cross two different rice lines (parents). Depending on the choice of parents, subsequent generations will exhibit a variety of genetic combinations that will provide the basis for future yield and quality advancements. Since the rice flower is perfect (contains both the male and female flower parts), a female flower must be created artificially by removing the male flower parts (anthers) from a rice floret. First the tips of the lemma and palea (hull) are snipped off to expose the floral parts (Fig. 2-1). The pollen bearing structures, the anthers, must be removed to prevent self fertilization. Normally, this is accomplished by using a small pipette connected to a vacuum pump that vacuums the anther out of the flower (Figs. 2-1, 2-2 and 2-3). This is a very tedious process that must be done in a meticulous manner to prevent abortion of the rice seed. The next step is to introduce pollen (male) from a different line and pollinate the female flower.

Over 1,000 such crosses are typically made at the Rice Research Station each year. The resulting seed from these crosses will contain genetic information from both parents. This seed is called the F_1 generation and germinated to produce F_1 plants. At maturity, seed is harvested from the F_1 plants. This seed is bulk-planted the following growing season to produce a population of segregating F_2 plants. Segregation means there is a great deal of variation in the appearance of these plants since they are expressing traits from both parents in many different combinations. The F_2 generation will exhibit more variation than any other population in the breeding process. Selection in the F_2 populations is a very important step in the variety development process. Breeders attempt to select those plants with the best combination of traits. Selection criteria generally include (but are not limited to) seedling vigor, maturity, height, tillering (number and uniformity), panicle size, completeness of panicle exsertion, grain shape and appearance, lack of grain chalk, disease resistance and overall plant appearance. Individual panicles are selected from those plants expressing the best combinations of the traits listed above for advancement to the next generation and beyond.

From this point on (F_3-F_n), most of the breeding material is grown as panicle (head) rows. A panicle row is a row of plants all derived from seed harvested from a single panicle. The best rows will be selected (not individual plants) to advance to the next generation. With each succeeding generation, the amount of segregation is decreased (or the level of uniformity is increased) both naturally and through the selection process. Thus, the F_4 generation is more uniform than the F_3 from which it was derived and the F_5 generation is more uniform than the F_4 generation and so on. Each year, approximately 95,000 to 120,000 panicle rows are grown at the Rice Research Station in the various breeding projects. Each of these rows is a unique genotype and any of them could theoretically become a new variety.

A tremendous amount of meticulous work must be done before these rows are planted. The seed from

Fig. 2-1. Preparing to remove the anthers with vacuum.

Fig. 2-2. Anthers being aspirated.

Fig. 2-3. Anthers removed. Floret emasculated.

each row must be individually threshed. A specialized panicle thresher is used to accomplish this, but it was not too many years ago that this was all done by hand. Specialized planters are also used to plant the individual rows. It requires a great many hours of careful work to prepare and arrange this seed for planting in such a way as to avoid mistakes.

Lines from most of the crosses have reached sufficient uniformity by the F_4 to F_5 generation to enter a line into a preliminary yield evaluation. Lines that are selected for potential yield evaluation are bulk harvested (after several panicles have been selected and harvested). Bulk harvesting of individual rows is done the "old-fashioned" way. Each selected row is harvested by cutting the stalks with a sickle and tying the harvested stalks with a length of twine. Each individual row is threshed, cleaned and dried on a small sample drier. Several thousand rows are handled this way each summer.

During the following winter, a number of laboratory analyses are conducted on each harvested sample (grain appearance and milling, cereal chemistry and seedling vigor), and the superior lines are entered into the initial yield testing program, which is called the Preliminary Yield Tests. Some of these are two-replication tests while a number of lines are evaluated each year in single plot tests. These trials are planted in March on the Rice Research Station. This planting time will allow a sufficient growing season to evaluate first and ratoon (second) crop performance. A "plot" in the Rice Breeding Project is seven drill rows spaced 8 inches apart 16 feet long (or approximately 75 square feet). This represents approximately 0.17 percent of an acre.

These small plots are used to keep the overall test as small as possible in an effort to minimize environmental variations that might influence the performance of genotypes (breeding lines) in the tests. It is critical that any differences expressed in these trials (yield, milling quality, height, etc.) are a result of true genetic differences and not caused by differences such as soil type, fertility or water depth.

Approximately 3 weeks after the preliminary yield trials are planted, a seed increase/purification block is planted that will include 9 to 14 headrows from each of the lines included in the yield trial. This increase block is planted later than the yield evaluations to provide time to analyze data and determine which lines may be advanced, and thus, which headrow populations should be harvested. Prior to harvest, these lines are evaluated and any segregating rows (rows with too much variation within the row) are removed from the population, 25 panicles are picked from a representative row, then the remaining seed is bulk harvested. The 25 panicles will serve as a pure seed source, and the bulked seed will provide enough seed for advanced testing in multilocation yield trials.

A typical preliminary yield test has 750 entries replicated twice for a total of 1,500 plots. These tests also include commercially grown varieties so that the performance of the experimental lines can be compared with these as well as to each other. Preliminary yield trials at the Rice Research Station utilize approximately 5 acres. If everything goes without a hitch, this test can be planted in less than a day with specialized planting equipment. However, preparing the seed for this planting (cleaning, cataloging, weighing, labeling and filling seed envelopes, laying out packets in planting order, etc.) is the result of many months of meticulous work during the winter. In addition, a great deal of data entry and recordkeeping is involved as lines move from one generation to the next.

After planting, this yield trial is managed similar to any other rice field to optimize production and uniformity throughout the test area. The process includes timely water management, fertilization and weed and insect control. Fungicides are not used in the breeding program because relative disease-resistance among the experimental lines is evaluated at every step of the variety development process.

These trials are evaluated at least twice weekly during the growing season, and data are collected for the following traits: (1) emergence date, (2) seedling vigor, (3) tillering characteristics, (4) heading date, (5) plant height at maturity, (6) disease susceptibility (any diseases present), (7) lodging characteristics and (8) harvest maturity date. When a plot reaches harvest maturity, a hand-harvested sample is taken for use in milling quality evaluation. This sample is cut with a sickle, threshed using a stationary thresher, aspirated (removing chaff and stems) and dried on a specialized sample dryer. This sample is taken this way because the entire test will be harvested with a small plot combine when all plots have reached harvest maturity. Since there may be up to 10 days difference in maturity among lines in these trials, taking a sample from each plot at harvest maturity puts all lines on an equal footing for milling quality evaluation.

Prior to harvest, all experimental lines are evaluated for relative susceptibility to major and minor rice diseases. Because we often do not have consistent disease pressure in these tests, these lines are also planted in disease nurseries where disease pressure is maximized by inoculation (sheath blight and bacterial panicle blight) and the use of highly susceptible spreader varieties (blast).

When all lines in a trial have reached harvest maturity, the trial is harvested using a specialized small plot combine. This combine has a 5-foot header width so it fits these plots perfectly. The combine has the capability to harvest a plot and automatically obtain the grain weight and grain moisture for the rice from that plot. The seed then can be bagged and tagged for identification. Under ideal conditions, the 1,500-plot test can be harvested in 2 days.

The hand-harvested sample is milled using specialized milling equipment that will provide data on whole and total milled rice. In addition, these samples are evaluated for uniformity, chalkiness, grain shape and any other characteristic that might be a factor in the acceptability of the line as a commercial variety. The multitude of data collected will be analyzed to decide which lines will be entered into advanced trials the following growing season.

Getting to the preliminary yield testing stage normally takes a minimum of 5 to 6 years from the time the cross is made. The lines that display superior characteristics in preliminary testing are considered for advancement to the Commercial-Advanced (CA) trials, as well as the Uniform Regional Rice Nursery (URRN). Only about 5 percent of lines entered into the preliminary trials will be advanced. The CA trials are conducted throughout the rice-growing regions of Louisiana. The off-station location trials are conducted in cooperation with rice producers who are willing to provide land, land preparation, irrigation and assistance with these trials in countless other ways. The farmer will provide an area that has independent flooding and draining capabilities. The trials are planted using the same small plot equipment that is used on the Rice Research Station. After emergence, the trial is handled just as it would be on the Rice Research Station to optimize production and minimize any environmental variation that would impact the ability to evaluate true genetic differences among the lines in the trials. These trials are evaluated at least weekly, and data are collected for all characteristics just as is done on the Rice Station. These trials are harvested using the small plot combine. Trials that are harvested prior to August 15 will be ratoon cropped to provide data on this important characteristic.

The URRN is a cooperative endeavor conducted by the public rice breeding programs in Arkansas, Louisiana, Mississippi, Missouri and Texas. The nursery is a yield-testing program that is conducted at the primary research location in each of those states. The “Uniform” refers to the fact that the same rice lines are tested at each of the five locations. The test normally contains 200 rice lines (or genotypes), each representing an elite line from each breeding program. Breeders submit lines that might have the attributes that would warrant their consideration as a new release. Among the 200 entries are several currently grown commercial varieties included to provide a standard of comparison. The yield test is conducted at the research station in each state using the best cultural practices for that region. All data from the testing program are provided to each cooperator. Most of the experimental lines in the CA trials are also entered into the URRN.

Therefore, between the CA and URRN trials, the most advanced experimental lines in the Louisiana program are evaluated in numerous yield trials each year. The CA and URRN trials are extremely important in making decisions on potential variety releases. It is critical that a line be evaluated under different environmental conditions to determine its area of adaptation. In a potential new variety, one is looking for superior and stable performance. Often, a line will have excellent performance in two or three of these trials but average or inferior performance in several others. This line will be eliminated because of the lack of stability. As with the preliminary trials, all of the entries in each of these trials are evaluated for relative susceptibility or resistance to major rice diseases.

Lines that show excellent yield potential and milling quality, a high level of adaptation and good agronomic characteristics across all these diverse environments will be reentered into these trials the following year. A line that shows good potential as a future release will also be included in the statewide Variety by Nitrogen rate testing program. These lines may also be evaluated for differential response to selected rice herbicides. This research is conducted so that if a line is released as a variety, a package of agronomic recommendations for its production is also available.

If a line displays significantly better performance than the current commercial varieties, it also may be grown as a larger headrow population as a step toward potential increase. In each generation of testing, these experimental lines are concurrently being grown as panicle rows for purification and increase. A typical headrow population for a potential release is approximately 1,000 rows, which is often grown at the winter nursery facility in Puerto Rico. A 1,000-headrow increase will provide enough seed for up to a 20-acre foundation seed field on the Rice Research Station.

Generally, at least three years of CA and URRN data are required before an experimental line is considered as a new variety release. Seed will be increased on superior lines during this same time period so foundation seed is often produced during the third year of testing. If the line consistently has shown superior and stable performance after the third year of advanced testing and adequate foundation seed is available, a comprehensive data package on the line is provided to the director of the Louisiana Agricultural Experiment Station. If, after reviewing the data, the director agrees this is a candidate line for release, a committee is appointed to evaluate the data and make a recommendation on the release. The final decision rests with the director. If the decision is made to release the line as a variety, the director will ask for suggestions and approve the name for the new rice variety. Appendix Table 2 outlines the sequence of events in the development of the rice variety Catahoula as an example of the procedure described above.

Rice variety development is a long-term process that demands a great deal of time, hard work and dedication by a large number of people within the LSU AgCenter. The rice breeding project depends heavily on many cooperating projects for assistance in the development and evaluation of experimental lines. Cooperators include agronomists, entomologists, pathologists, biotechnologists, geneticists, weed scientists, food scientists and physiologists. This cooperation is essential for the success of varietal improvement efforts aimed at numerous characteristics, including but not limited to yield, milling quality, cooking quality, insect resistance, disease resistance, herbicide tolerance, seedling vigor, lodging resistance, fertilizer responsiveness, stress tolerance, earliness and ratooning.

The Rice Breeding and cooperating projects also evaluate potential varietal releases from other breeding projects (both private and public) to determine their adaptability under Louisiana growing conditions. Many rice varieties from out-of-state breeding programs are well adapted to Louisiana and are widely grown.

Rice Variety Characteristics

The two primary grain types grown in Louisiana are long grains and medium grains. Long grains are characterized by a grain length:width ratio of more than 3:1 and typically cook dry and fluffy because of a high- to intermediate-gelatinization temperature characteristic and a relatively high amylose content. Medium grains typically have a length:width ratio of between 2:1 and 3:1 (usually closer to 3:1) and cook soft and sticky because of a low gelatinization temperature characteristic and a relatively low amylose content. Southwest Louisiana producers have historically planted from 20 to 50 percent of rice acreage in medium grains, and those in northeastern Louisiana grow almost exclusively long-grain varieties. Due to market demands, the percentage of the state rice acreage planted to medium grains has continually decreased. In recent years, less than 10 percent of Louisiana rice acreage has been seeded to medium-grain varieties.

Interest in special-purpose varieties has increased in recent years. These varieties have distinctly different cooking attributes, such as aroma, elongation or unique cooking characteristics that may be favored by many ethnic populations living in the United States, as well as other consumers interested in gourmet or premium rice. The major specialty types include soft cooking aromatic Jasmine, flaky cooking elongating and aromatic Basmati, Kokuhoe, waxy, standard long-grain aromatic Della, soft cooking non-aromatic Toro and other less known gourmet types. Most specialty rice marketed in the United States is imported from Thailand, India and Pakistan. The Rice Research Station has been successful in developing and releasing a number of specialty varieties in recent years, including Della, Jasmine, Basmati and Toro types.

Development of Hybrid Varieties

Hybrid rice, produced from the first generation (F_1) of seeds between a cross of two genetically dissimilar pure line (inbred) parents, represents a relatively new option for Louisiana farmers. Commercial hybrids typically yield 10-20% more than the best inbred varieties grown under similar conditions believed to be the result of "hybrid vigor" or "heterosis" from crossing the two parents. The heterosis advantage of hybrids may be expressed by superiority over inbred varieties in grain yield, vigor, panicle size, number of spikelets per panicle, and number of productive tillers. To exploit the benefits of hybrids, farmers normally purchase seed from commercial companies for each cropping season.

Hybrid varieties are generally developed by the "three-line" or the "two-line" breeding method. For the three-line method, the Hybrid Breeding Project generates 200-300 crosses each year for development of cytoplasmic male sterile (A), maintainer (B), and restorer (R) lines used in the production of hybrids. The cytoplasmic male sterile lines do not produce viable pollen; therefore serve as the female parent in hybrid crosses. Because the A line cannot produce viable pollen it must be crossed with another source, the maintainer or B lines to provide A line seed for the future. A and B lines are crossed in an isolation plot to maintain a supply of seed of the A line. Hybrid seeds are produced by crossing an A line with a suitable R line in separate isolated plots. The R line both restores fertility to the seed harvested from the A line and provides desirable traits in the resulting hybrid.

In the two-line method, certain lines, referred to as S lines, can be either male sterile (functionally female) or male (produces viable pollen) depending upon temperature and day length. Under one set of temperature/day length combination, the S lines are crossed as females to fertile inbred lines to produce hybrid seed, while under separate temperature/day length combination, the same lines are allowed to self-pollinate and produce viable seed to maintain a source of the line. Use of S lines in this manner eliminates the need to develop maintainer B lines that are required in the three-line method but requires two different temperature/day length combinations be possible either in the field or in an artificial environment.

To develop and evaluate new A, B, R, and S lines used in producing new hybrids, agronomic and management data are collected from various nurseries and field trials located at university field plots and farmers' fields across Louisiana. The Observational/Testcross nursery evaluates 600-1000 new F_1 hybrid combinations each year at the Rice Research Station in one or more short rows along with three to five inbred and hybrid check varieties. The hybrids and checks are evaluated for grain production, height, maturity, lodging, disease and insect resistance, and milling and appearance traits to identify elite A, B, R, and S lines.

Hybrids that yield 15–20% higher than the check varieties in the Observational/Testcross nursery are advanced to the small-plot Preliminary Yield Trial at the Rice Research Station. Data on agronomic traits, yield, disease and insect resistance, and grain quality are recorded. Outstanding hybrid entries in the Preliminary Yield Trial are also screened for milling and grain appearance and cereal chemistry. Superior lines are then evaluated in Multi-location Yield Trials in five or more parishes across Louisiana. Grain yield and other agronomic data are recorded. To assess adaptation and productivity in Louisiana and other states, superior hybrids identified from the Multi-location Yield Trials may be entered into the Uniform Regional Rice Nursery (URRN) trials.

For commercial production of hybrid seeds, an A or S line is used as a female and planted in ~ 10 rows bordered by 3 rows of fertile male plants on each side that pollinate the female. These fields must be isolated to avoid pollination from other sources. The female rows are harvested to produce bulk quantities of hybrid seed.

The potential for hybrid rice in Louisiana is good, but there are several challenges, including but not limited to, lodging, maturity, whole-grain milling yields, grain appearance, and shattering (grain retention). The Rice Research Station is currently engaged in breeding research to address these challenges.

For additional updated varietal information, check the Extension Service's publication 2270, "Rice Varieties and Management Tips," which is revised each year.

Foundation Seed Production

Once a variety has been released by the LSU AgCenter, a mechanism is needed to purify, maintain and distribute high quality, genetically pure seed of this variety to the rice industry. Seed certification accomplishes this and provides an operating procedure to guarantee a source of high quality seed to the user. The field and laboratory purity standards for seed rice certification are very strict with regard to varietal mixtures and noxious weeds. In all phases of production, therefore, great care must be exercised to prevent these impurities from contaminating the seed stocks. The foundation seed rice program at the Rice Research Station is the first step in the seed certification process.

A small amount of seed of a new variety is supplied by the breeder to the foundation seed program. Seed harvested from individual rice panicles are grown in separate identifiable rows (one panicle per row) called headrows. This allows the breeder and foundation seed personnel to purify lines and discard mixtures, off-types or outcrosses and maintain identity of potential variety releases. Acceptable headrows are combined in bulk to produce breeder seed, which is maintained by the foundation seed program and used to plant the next stage in the seed certification process. The foundation seed program plants this small amount of breeder seed from which foundation seed is harvested.

Allocation of foundation seed rice in Louisiana is directed by the Louisiana Seed Rice Growers Association. It is allocated to Louisiana producers by a formula based on the previous year's rice acreage in each parish. For example, if the acreage of a parish represents 20 percent of the total rice acreage in the state in that year, 20 percent of the foundation seed of each variety available the following year will be allocated to that parish. After these initial allocations are met in each parish, any remaining seed is offered to producers whose requests were not met initially. If any seed remains after the requests of all Louisiana producers have been met, seed then is sold to out-of-state seed growers.

Grain harvested from foundation seed is certified and sold as registered seed. Registered seed is used to produce the last generation, certified seed. In some instances, certified seed may be produced directly from foundation seed. Certified seed is used by farmers to plant rice crops for milling and cannot be used to produce seed in the seed certification process.

The official seed certifying agency in Louisiana is the Louisiana Department of Agriculture and Forestry. This agency establishes the guides for all aspects of the certification process. All levels of the certification process from breeder seed to certified seed are monitored, inspected and tested by the Louisiana Department of Agriculture and Forestry.

Chapter 3

Soils, Plant Nutrition and Fertilization

Dustin Harrell and Johnny Saichuk

Rice requires an adequate supply of plant nutrients throughout the growing season. Four major nutrients and one micronutrient are critical for high-yielding rice in Louisiana. Nitrogen is required on all rice-producing soils, and N is the single most important nutrient necessary for maximizing yields. Rice also requires relatively large amounts of phosphorus (P) and potassium (K) on certain soils, especially the prairie and flatwoods soils of Southwest Louisiana. The alluvial soils (clay and clay loams) in central and northeast Louisiana are typically high in these nutrients and do not respond to P and K applications. Deficiencies in P and K can occur on alluvial soils where topsoil has been removed by land-forming operations. Sulfur (S) is adequately supplied by most rice soils unless native fertility is inherently low (typical in coarse texture low, organic matter topsoil) or topsoil has been removed. Zinc (Zn) is the only micronutrient known to be deficient on some Louisiana rice soils. As with S, Zn deficiencies occur when native levels are low, where topsoil has been removed, pH is high or when cool weather retards root growth during the seedling stage.

Behavior of nutrients in rice is quite different from that of upland crops. Because rice is cultured under flooded conditions, the relationship between nutrient availability and flooded soils must be understood to manage these nutrients properly.

Nitrogen

Inorganic N in the soil can be found in both the ammonium-N and nitrate-N forms. Rice plants are capable of using either form of N. Once a rice soil is flooded the soil will change from an aerobic (with oxygen) to an anaerobic (no oxygen) state. Nitrate-N is unstable and can quickly be lost through denitrification under anaerobic, flooded conditions. On the other hand, ammonium-N is very stable under flooded (anaerobic) conditions and will remain available to plants as long as the flood is maintained. If a rice soil is drained and re-oxygenated ammonium-N can be transformed to nitrate-N through a process called nitrification.

When the soil is reflooded, nitrate-N will be lost rapidly. Therefore, only ammonium fertilizers (like ammonium sulfate) or ammonium forming fertilizers (like urea) should be used in rice production. Once the N fertilizer has been applied, the permanent flood should be established and maintained throughout the growing season to maximize nitrogen use efficiency.

Phosphorus

Soil P is present in both the organic and inorganic forms. As with all nutrients required by rice, organic forms are not immediately plant available. Since organic P is slowly converted to the inorganic form, P fertilizer applications are very important on soils deficient in this nutrient. Flooding a rice soil increases the availability of soil P to plants. However, alternating flooding and draining cycles has a significant impact on P availability. When the soil is drained and aerated, P availability to plants is often decreased. Reflooding on the other hand will enhance P release.

Potassium

Soil K is affected less by flooding than N or P. Availability of K changes very little with draining and flooding. In Louisiana soils, K is less often found limiting to growth and grain yield as compared with N and P. Potassium nutrition is closely associated with the rice plant's ability to resist disease, and more emphasis is being placed on the role it plays in overall rice plant nutrition.

Sulfur

Most of the S contained in the soil is in the organic form under flooded and nonflooded conditions. Inorganic S originates from the decomposition of organic matter, and the S status of a soil is related to the amount of organic matter present. Some S is also provided by rainfall and irrigation water.

Zinc

Zinc availability is affected by flooding, although the change in soil pH in response to flooding accounts for the fluctuation in available Zn. Zinc is more available when the soil pH is acidic. After soil is flooded, its pH will drift toward neutral, thus an acidic soil becomes more alkaline and an alkaline soil becomes more acidic. This means that when acidic soils are flooded Zn will become less available, and when alkaline soils are flooded, it will become more available.

Other Nutrients

Many other nutrients play a role in rice plant nutrition, and flooding has differential effects on their availability. Availability of calcium and magnesium is not greatly affected by flooding. Iron (Fe), magnesium (Mg), boron (B), copper (Cu) and molybdenum (Mo) become more soluble under flooded conditions. While these nutrients are known to play a role in rice plant nutrition and critical levels in rice plant tissue have been established, documented deficiencies or toxicities have not been recognized in Louisiana.

Rice Plant Nutrition and Fertilization

The most frequently limiting plant nutrients in Louisiana rice in order of importance are N, P, K, Zn and S. Soil type, native soil fertility, cropping history and agronomic management practices determine when and to what extent deficiencies of these nutrients occur. A soil test is valuable in predicting nutrient deficiencies and the measures appropriate for correcting deficiencies. A sound fertility program is essential to maximize yields and efficient use of plant nutrients. Many nutrient deficiencies can be corrected in the field, but providing sufficient amounts of required nutrients to avoid deficiencies is the best approach to ensure maximum rice yields.

Proper fertilizer management is important to increase profitability, minimize inputs, improve nutrient efficiency and mitigate environmental concerns. Efficient fertilizer use requires: (1) proper water management in relation to fertilizer application; (2) selection of the proper fertilizer source; (3) timely application of fertilizers by methods that provide optimum rice growth, grain yield and crop quality and (4) application of the proper amount of fertilizer to ensure optimum grain yields and economic returns. The major plant nutrients required for rice production and their proper source, time of application and rate are discussed in the following sections.

Nitrogen Nutrition, Water Management, Source and Timing

Nitrogen is the most limiting plant nutrient in rice, and maximum yields depend on an adequate supply of N. Deficiency symptoms include yellowing of the older leaves, reduced tillering, browning of leaf tips and shorter plants (Fig. 3-1). Efficiency of N fertilizer applications can be reduced due to losses from soil via nitrification-denitrification, volatilization and/or leaching. Research in the southern United States examining the influence of application timings and N management strategies commonly reported N recovery of 17 to 79 percent of the applied N at rice maturity.

Several environmental and cultural factors affect the uptake and use of N by rice. Depending on the N source, N could be lost before the rice plant even has a chance to begin absorbing it through the roots. Current rice varieties respond well to large amounts of N fertilizer, but these varieties are not totally immune to the problems in older varieties associated with over-fertilization. For example, excessive vegetative growth, lodging, disease damage, delayed maturity and reduced grain yields of lower quality can occur if N fertilizer applications are made at unnecessary rates or at the wrong growth stage. Because of the relation between N behavior and flooded soils,

Fig. 3-1. Nitrogen deficiency.

the efficiency of N fertilizer applications in rice is greatly influenced by water management.

Rice is a semiaquatic plant that has been bred and adapted to flooded culture. Flooding a rice soil (1) eliminates moisture deficiency, (2) increases the availability of most essential plant nutrients, (3) minimizes weed competition and (4) provides a more favorable and stable microclimate for plant growth and development.

A permanent flood of 2 to 4 inches should be established as soon as possible and maintained throughout the growing season. In dry-seeded rice, the permanent flood is established by the 4- to 5-leaf rice stage (20 to 35 days after planting). Uniform, level seedbeds allow earlier flooding, which improves nutrient availability and weed control. To avoid stand loss and reduced seedling vigor, dry-seeded rice should never be submerged by the floodwater. In water-seeded rice, a shallow flood is established before planting. Rice seedlings either emerge through a permanent flood (continuous flood system) or the field is briefly drained to encourage seedling anchorage and uniform stand establishment (pinpoint flood system). The field then is reflooded, and seedlings emerge through the floodwater as in the continuous flood system.

Draining rice fields after permanent flooding should be avoided unless extenuating circumstances exist. Removing the floodwater can result in loss of N, affects the availability of many other nutrients, encourages weed emergence and growth, and increases the incidence of some diseases. Situations that justify draining include: (1) soils conducive and/or varieties susceptible to straighthead, (2) severe Zn deficiency is observed or expected, (3) is required for application of certain herbicides or (4) field is infested with rice water weevil larvae.

The development of Clearfield rice varieties has added a new dimension to rice production in Louisiana. This technology has prompted many rice producers in the state to change at least a portion of their acreage from the traditional water-seeded system to a drill-seeded system. Both the water- and drill-seeded systems place unique restrictions on N fertilizer management, but the essential components of a successful N management plan are the same for either system. In developing a successful N fertilizer management plan, the source of N fertilizer, the placement of fertilizer in the field, the application rate and application timing should all be carefully considered.

Ammonium sulfate and urea are the most common sources of N used in rice, and these two sources are equally effective when properly applied. Urea is the most common and best source of N for rice. Its relatively high N analysis (46 percent) compared with other N fertilizer sources also makes urea the most economical N source since less material is applied per unit of N. Urea is prone to losses through ammonia volatilization if applied to a moist soil or if left on the soil surface for an extended period (more than 3 to 5 days) after application.

Nitrogen fertilizer applied as urea is prone to loss through ammonia volatilization. Use of a urease inhibitor delays breakdown of urea, minimizing N loss associated with ammonia volatilization. This will improve N efficiency when urea is applied on a wet soil surface before permanent flood or when urea is applied to soil surface more than 3 days before permanent flood establishment. Results may vary with year and/or environment.

Ammonium sulfate contains 21 percent N, so more than twice the amount of fertilizer material is required per unit of N. However, it is a good choice if soil tests recommend S because it contains 24 percent S. If ammonium sulfate is used strictly as an N source, it is less desirable than urea because its price per pound of actual N is much higher than urea. Research has shown that ammonium sulfate may be a slightly more effective N source than urea when N must be applied to saturated soils during the seedling stage because volatilization occurs at a much slower rate than urea. Nitrate-N should never be used in rice because of the potential for large losses of N caused by leaching and denitrification.

Another N source popular for rice in Southwest Louisiana is a 50 percent blend of urea and ammonium sulfate, which has a N analysis of approximately 33 percent. This combination combines the positive traits of both sources—it is less prone to volatilization than urea and has a higher N analysis than ammonium sulfate. The mixture is still subject to ammonia volatilization at a slower rate; however, the mixture has 13 percent less total N than urea.

Ammonium-N is very stable in flooded soils and remains available throughout the season. Following N application and flooding, soil drying should be avoided or ammonium-N will be converted to nitrate-N. This conversion process results in loss of N through denitrification when the field is reflooded.

The proper application rate for N fertilizer depends on rice variety, stand density, previous crop, straw management, fertilizer source, application method, water management, soil texture, soil pH and tillage system. Therefore, a clear definition of N requirements for rice is difficult to formulate. Historically, total N requirements are determined by conducting statewide variety by N trials. Recently, a new soil test for N has been developed which can aid in determining the N needs for rice grown in the mid-southern United States. The nitrogen soil test for rice, coined N-STaR, has separate calibration curve for silt loam and clay soils. Fertilizer N recommendations, generated from the N-STaR extraction, are being validated on commercial rice fields and are currently not a recommended practice in Louisiana. However, the use of N-STaR has become a recommended practice in Arkansas.

Current N recommendations in Louisiana are provided as a suggested rate range. For a given rice variety, the N rate range encompasses all soil types and environments. Previous knowledge of the productivity of a particular field should be used by the producer to fine tune the N recommendation within the range on a field-by-field basis. Most rice varieties grown in the United States require 120 to 180 pounds of N per acre to produce acceptable grain yields with good milling quality, and in some cases, 30 to 60 more pounds of N per acre will be required for a variety when grown on a clay soil than a silt loam soil. This information is updated annually in the LSU AgCenter publication 2270, “Rice Varieties and Management Tips.”

Nitrogen fertilizer application timing depends on the cultural system used for rice production. A continuous, available supply of N must be maintained in the soil-plant system to maximize production. The relationship between N fertilizer application timing and water management impacts N retention, efficiency and use. The approaches to N management in a permanently flooded system (continuous or pinpoint) and a delayed flood system (dry-seeded or water-seeded with a delayed flood) are quite different. When N fertilizer is applied early in the growing season, the fertilizer must be placed where it is least prone to loss and most readily absorbed by the plant. Therefore, the N fertilizer must be incorporated into the soil. In a drill-seeded system, the majority of the N fertilizer should be applied to the soil surface and incorporated with the floodwater as the permanent flood is established. Regardless of whether rice is water seeded or drill seeded, the uptake of N early in the season is critical and affects uptake of N throughout the remainder of the season. So, for optimum growth and yield, the N supply should be adequate during the tillering stage of rice development.

In permanently flooded systems, all or most of the total N requirement should be incorporated into a dry soil 2 to 4 inches deep prior to flooding. Brief drainage following seeding to encourage seedling anchorage in a pinpoint flood system will not result in excessive N loss unless the soil is permitted to dry and aerate.

The majority of the N fertilizer could be applied during the initial drain period in a pinpoint flood system and incorporated with the floodwater following seedling anchorage. The seedbed must be maintained in complete saturation to conserve applied N fertilizer.

Regardless of the water management system, additional N fertilizer can be applied at midseason at the beginning of reproductive growth between panicle initiation [PI, green ring (Fig. 4-10) or beginning internode elongation (IE)] and panicle differentiation (1/2 inch IE) (Fig. 4-11) as needed unless the total requirement was applied preplant incorporated.

In the delayed flood systems (dry broadcast, drill- or water-seeded), the permanent flood may not be established until 3 to 4 weeks after seeding. It is impractical to apply large amounts of N fertilizer at seeding in these systems since it cannot be stabilized or maintained before permanently flooding. Starter N fertilizer applications can be used in delayed flood rice production systems as a surface broadcast application and should be limited to 15 to 20 pounds of N per acre. The starter fertilizer N application encourages rapid growth and development of seedling rice and often results in rice which can be flooded a week earlier as compared with rice which does not receive a starter N application. This can be very beneficial in a weed control program. Research has shown that starter N applications in rice rarely result in increased yield at the end of the season. Surface broadcast applications of N fertilizers are inefficient and are subject to loss and should not be counted toward the total N requirement for the entire season. All or most of the required N fertilizer should be applied to a dry soil by the 4- to 5-leaf rice stage prior to permanent flood establishment. The floodwater solubilizes the N and moves it down into the soil where it is retained for plant use during the growing season. Additional N fertilizer can be applied at midseason at the beginning of reproductive growth between PI and PD as needed unless the total amount required was applied preflood.

One problem with preflood applications of urea is the potential for it to turn into ammonia (NH_3) gas and simply float off the field if it is left exposed on the soil surface for an extended period of time. This process is called ammonia volatilization. Studies conducted in Louisiana over the past several years

Fig. 3-2. Straighthead symptoms.

have shown that when urea is left on the soil surface for 10 days, volatilization losses can range from 17 percent to 25 percent. Unfortunately, it may take 10 or more days for a flood to be established on large commercial rice fields. In this situation, a urease inhibitor containing the active ingredient N-(n-butyl) thiophosphoric triamide, or NBPT for short, is recommended. Urease inhibitors come in a liquid form and are applied on urea at the fertilizer distributor. The urease inhibitor basically slows down the breakdown of urea to the ammonium-N form. Because it temporarily delays the breakdown of urea, it also temporarily delays the potential for ammonia volatilization losses. The economic breakeven point for the use of a urease inhibitor product varies yearly due to the cost of the urease inhibitor, cost of urea, and rate of volatilization. In general, the breakeven point generally occurs between 3 and 5 days. The use of a urease inhibitor product will be economically beneficial in most years when it takes longer than 5 days to flood a particular rice field. In order to maximize N use efficiency, it is imperative to make sure the urea is applied only on dry ground and then flooded. When urea is applied to damp ground the initial rate of volatilization is increased. The use of a urease inhibitor will help in this scenario; however, it is only half as effective as compared to dry-ground applications. A urease inhibitor will not be beneficial if the treated urea is applied into the flood water at the preflood fertilization timing.

In either a permanent or delayed flood system, an adjustment in N management is necessary when rice fields are drained for straighthead. Straighthead is a physiological disorder (Fig. 3-2) that occurs on sandy soils, on soils where arsenical herbicides have been previously applied, on soils that have not been in rice production for several years and on soils where large amounts of plant residue have been incorporated prior to planting. Significant yield losses can result from straighthead if fields are not drained and completely aerated before PI. Draining detoxifies arsenical compounds and reduces the buildup of hydrogen sulfide. Since draining usually occurs during midtillering, no more than 60 to 70 percent of the required N fertilizer should be applied preplant or preflood, with the remainder applied before reflooding.

Research indicates the total N fertilizer requirement can be applied preplant in a continuous flood system or preflood in a delayed flood system. Newer rice

Fig. 3-3. Phosphorus deficiency.

Fig. 3-4. Left, normal plant. Right, phosphorus-deficient plant.

varieties can absorb enough N for high yields from a single application of the total N requirement applied; however, applying the entire amount of N in one application is not always feasible, i.e., aerial application. Uniform N fertilizer application, knowledge of the varietal N requirement, experience with a particular soil and proper water management are critical when using single preplant or preflood applications. This approach may not be practical commercially when (1) uniform application of large amounts of N fertilizer is difficult, (2) water management capabilities are inadequate, (3) the producer is unfamiliar with the variety or field history, (4) if the field has a history of straighthead and (5) the seedbed is saturated. Split applications may be required when any of these conditions exist.

Midseason N topdressing applications are used efficiently by rice if inadequate early season N fertilizer was applied. A single, midseason application is usually sufficient to maximize yield. Multiple applications of midseason N fertilizer may not be cost effective and could reduce yield if the basal N fertilizer application was inadequate. Unlike N fertilizer applications into the floodwater on seedling rice, N fertilizer applied into the floodwater at midseason is used efficiently by rice because of its large plant size and extensive root system.

Rice plant growth stages have been used to determine when to apply midseason N fertilizer. The green ring growth stage (internode elongation) traditionally has been used for timing midseason N fertilizer applications. Although this growth stage is a good indicator, the overall health of the rice crop before green ring formation must be considered. Tissue analyses and visual assessment are excellent diagnostic tools to determine the N status of rice at midseason growth stages. Nitrogen deficiency should be avoided to minimize the potential for grain yield reductions. Midseason N fertilizer should be applied at the earliest indication of N deficiency, even if the green ring growth stage has not occurred. Late-season N fertilizer applications also may be inefficient and could lead to grain yield reductions. Research indicates that grain yields are not improved when N fertilizer is applied later than 4 weeks following green ring.

Ratoon or second crop rice should be fertilized with 75 to 90 pounds of N per acre when main-crop harvest is before August 15. When conditions are favorable for good ratoon rice production (minimal field rutting, little or no red rice, healthy stubble), the higher N fertilizer rate should be used. The N fertilizer should be applied and a shallow flood established within five days after harvest. Research has consistently shown that N fertilizer should be applied and the field flooded as soon as possible after main-crop harvest to maximize ratoon rice yields. When main-crop harvest is after August 15, the ratoon N fertilizer application rate should be reduced by approximately 5 pounds a day past August 15.

Phosphorus Nutrition, Water Management, Source and Timing

Phosphorus deficiencies in rice occur infrequently compared with N deficiency. Stunting, reduced tillering, delayed maturity and yield reductions can occur when P is limiting (Fig. 3-3 & 3-4). Unlike N, water management has little impact on P retention unless soil loss occurs through erosion or removal of floodwater containing high sediment concentrations. Phosphorus availability is influenced by fertilizer placement, soil factors (pH, Fe, aluminum, and calcium content), and wetting/drying cycles. Flooding increases P availability to rice, but alternating wetting and drying cycles can result in fixation of P in the soil and temporary deficiency.

Water soluble sources of P, such as triple superphosphate and diammonium phosphate, are effective in preventing and correcting mild P deficiency symptoms. Cost effectiveness and the requirement for other nutrients should be considered when choosing a P source. Factors to consider when determining the P application rate include soil type, cropping history, producer experience and soil and plant tissue analyses. Typical P application rates range from 20 to 60 pounds per acre.

Phosphorus is most available to rice when applied at planting as a band or broadcast and incorporated application in the spring prior to planting. If preplant applications are not possible, P should be applied prior to tillering. Since adequate P is essential for tiller formation, P deficiencies at this growth stage can reduce yield significantly. Research indicates that fertilizer applications to P-deficient soils are less effective after tillering has begun (4 to 5 weeks after planting).

Potassium Nutrition, Water Management, Source and Timing

Rice plants deficient in K appear a lighter green than healthy plants, and the leaf edges contain rust-colored spots that give the plant a brown appearance (Fig. 3-5). Plant height may be reduced. The role of K in plant nutrition is very important as it relates to disease resistance.

Potassium behavior in the soil is influenced little by water management. Potassium is a very soluble nutrient and is accumulated by the rice plant throughout the growing season. Preplant or early season K application in conjunction with N or P is recommended. Potassium chloride and K sulfate are common K sources to correct existing deficiencies. A single K application (20 to 60 pounds per acre) is usually sufficient to maintain adequate K in rice plants. Split applications are not required unless the soil is very sandy and leaching occurs. Furthermore, since most rice soils, even those with a sandy plow layer, contain a clay hardpan that restricts water infiltration, split applications are seldom necessary.

Sulfur Nutrition, Water Management, Source and Timing

Sulfur (S) deficiency is difficult to diagnose because it resembles N deficiency. Unlike N, S is less mobile in the rice plant. Rice plants deficient in S begin to yellow from the newest leaf to the oldest leaf, where as N deficient plants begin to yellow from the oldest leaves to the newest leaf. Once the entire plant becomes yellow, it is very difficult to determine if the plant is deficient from S or N without plant analysis. Inadequate S in the soil and removal of topsoil during land-forming operations contribute to S deficiencies. A soil test can aid in identifying soil areas where S deficiencies might occur. Ammonium sulfate (21-0-0) is an excellent source of S for correcting existing deficiencies. An application of 100 pounds of ammonium sulfate per acre will supply 24 pounds of S, which is an adequate amount to avoid or correct S deficiency in an existing crop. Water management has no effect on S availability or retention in soil but may be important in relation to application of S-containing N fertilizers. Only S in the sulfate form should be used in rice production once S deficiency symptoms occur. Although, elemental sulfur fertilizer sources contain a higher amount of S per pound of fertilizer (generally 90percent S) the S is not immediately plant available.

Zinc Nutrition, Water Management, Source and Timing

Zinc deficiency is a common micronutrient problem in rice. Early deficiency symptoms include chlorosis and weakened plants that tend to float on the floodwater surface (Fig. 3-6). Dark brown spots develop on the leaves, and when deficiency is severe, stand loss occurs. Zinc deficiency is usually referred to as bronz-

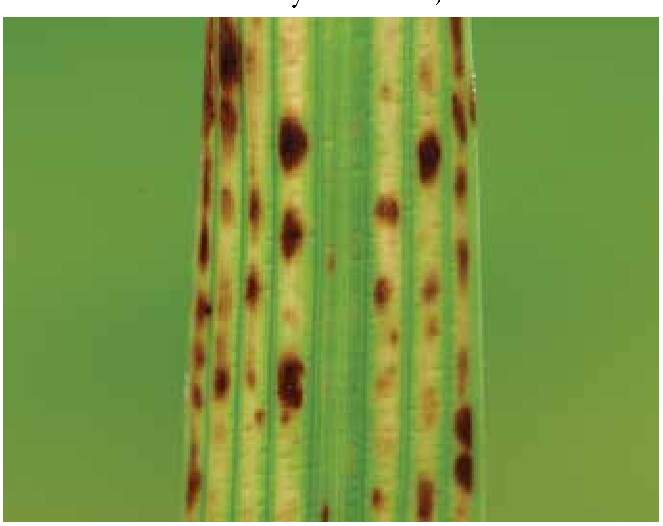


Fig. 3-5. Potassium deficiency symptoms on leaf.

Fig. 3-6. Typical zinc deficiency symptoms.

ing because of the rusty appearance that develops. Calcareous soils with an alkaline pH, inadequate Zn levels in the soil, removal of topsoil during landforming, excessive lime applications, deep water during seedling growth and cool weather that retards root growth during the seedling growth stage may all contribute to Zn deficiency. Deficiencies most often occur in early planted, water-seeded rice because of low temperatures and poor root growth. Since stand loss can occur when deficiency is severe, deficiency symptoms must be recognized early.

A soil test can identify soils prone to Zn deficiency. Inorganic Zn salts, such as Zn sulfate, may be applied with other required fertilizer nutrients at planting. In dry-seeded rice, Zn should be incorporated to a shallow depth. In water-seeded rice, Zn is more available when applied to the soil surface in close proximity to the developing root system.

Plant uptake of Zn is affected by temperature and root growth. Preplant Zn applications do not guarantee that deficiencies will not occur. If Zn deficiencies begin to develop in seedling rice, corrective applications need to be considered. Favorable growing conditions (high temperatures and sunlight) or removal of the floodwater may help correct mild Zn deficiencies. When Zn deficiency is severe and the potential for stand loss exists, apply Zn fertilizer as a foliar application.

Either inorganic salts or chelated forms of Zn may be applied preplant. Inorganic forms, such as zinc sulfate, should be applied at a rate of 5 to 15 pounds of actual Zn per acre. Although, rice takes up less than one pound of Zn per acre, adequate distribution of Zn from granular fertilizers requires higher application rates. It is important that Zn fertilizer sources are at least 50percent water soluble or higher rates of Zn will need to be applied. Zinc oxide forms should be avoided for in-season applications. Soil applied liquid Zn sources (>50percent water soluble) can be applied at rates of approximately one-half of that recommended for granular sources. Chelated Zn sources are preferred for soil applications. In-season, foliar Zn applications can be applied at a rate to deliver 1 to 2 pounds of actual Zn. If Zn deficiency occurs while the rice is flooded, it is best to drain the field and let the rice recover prior to foliar Zn application. Once applied, additional N may need to be applied to compensate the N that will be lost after flooding; generally ammonium sulfate is the preferred source in this situation. Granular applications of zinc sulfate are also equally as effective as foliar applications in this type of situation since it is 100percent water soluble.

Fall Fertilizer Applications

Fertilizer nutrients are most efficiently used by rice when applied immediately before seeding and no later than permanent flooding. There are situations when a fall application of some nutrients may be a suitable alternative. These include: (1) no-till and stale seedbed rice production when soil incorporation at planting is not possible, (2) rice fields worked in the water prior to planting when there is concern of fertilizer movement and nonuniform redistribution after mudding in and (3) where scumming is a problem when fertilizer is applied into the floodwater on seedling rice. Advantages to fall application of P and K include more flexibility in early season N applications and more opportunity to apply these nutrients by ground application. Disadvantages include poor retention of K on sandy soils because of leaching and fixation of P on low pH soils containing high levels of Fe and aluminum. Never apply N and Zn in the fall.

Soil Testing

One of the key elements of a successful fertilization program for Louisiana-grown rice is the use of a soil test. Soil test data provide an estimate of plant-available nutrients that can be used to generate fertilizer recommendations. Soil test calibration studies are conducted annually by LSU AgCenter personnel to improve and validate soil test-based fertilizer recommendations. Currently, there is a calibrated soil test(s) for all major and minor plant essential nutrients with the exception of N. Nitrogen fertilizer recommendations for rice are variety based and can be found in the rice fertilization section of LSU AgCenter publication 2270, “Rice Varieties and Management Tips.”

A quality soil test begins with a representative soil sample. It is often said that a soil test is only as good as the sample that is sent to the soil testing laboratory. Soil samples should be grouped into areas with similar soil texture, organic matter content, elevation, etc. Other areas to pay particular attention to in a rice field include areas near water inlets, drains and areas where large amounts of top soil have been removed and/or moved during the land leveling process. A soil test should never represent an area larger than 20 acres.

Once an area is defined, several cores are needed from that area to create a composite sample. To take a composite sample, simply take several soil cores using a soil test probe randomly throughout the designated area and mix them in a bucket or other container. Cores in a rice field should be taken to depth of the plow layer and/or to the depth of the natural hardpan, which generally occurs from 4 to 6 inches. Once enough cores are taken to adequately represent the area, mix the soil thoroughly and pour approximately 1 pint of the soil into a complimentary soil test container or zipper-type storage bag. Soil test containers are available at your local county extension office or directly from the LSU AgCenter Soil Testing and Plant Analysis Laboratory. A completed soil test form and a check for requested analyses should accompany all soil samples. Samples can be turned in to your local extension office or mailed directly to the soil testing laboratory. All needed forms can be found online at the LSU Soil Testing and Plant Analysis Laboratory Web site (www.stpal.lsu.edu).

Soil samples should be taken and tested every two to three years during the fall. Sampling in the fall allows sufficient time for the laboratory to chemically analyze the soil and return the results to you in a timely fashion. This, in turn, gives you more time to plan the fertilization for your spring rice crop based on the recommendations provided by the laboratory.

The most important nutrients to pay attention to on your soil test report for a rice crop include P, K, S and Zn. The LSU AgCenter Soil Testing and Plant Analysis Laboratory provides fertilizer recommendations for these and other nutrients on their basic soil test recommendation sheet. Although the AgCenter recommends using its own soil testing laboratory, some producers may choose to use a private out-of-state soil testing laboratory. For this reason, the soil test-based fertilizer recommendation tables have been included in this text. These tables can be used to generate fertilizer recommendations with soil test results from private laboratories. These tables were generated based on several years of fertilizer response trials on Louisiana rice soils. These tables are periodically updated based on new research results. It is important to check the online version of this manuscript to see if recent changes have occurred since the initial publication.

Prior to using one of these soil test-based fertilizer recommendation tables, it is important that you validate that the soil test extraction used by the private laboratory is the Mehlich-3 soil test. Other soil test extractions are not compatible with the following recommendation tables (Tables 3-1 to 3-4). Second, you must make sure that the soil test results are in parts per million (ppm). To change pounds per acre to parts per million, simply divide the number by 2.

Table 3-1. Phosphorus (P) fertilizer recommendations for rice grown on Louisiana soils based on the Mehlich-3 soil analysis.

	Soil Test Category			
	Very Low	Low	Medium	High
		ppm		
Mehlich-3 Extractable P	<10	1 - 20	21 - 35	≥36
		lb P_2O_5 / Acre		
Fertilizer Recommendation	60	40	20	0

Table 3-2. Potassium (K) fertilizer recommendations for rice grown on Louisiana soils based on the Mehlich-3 soil test.

Soil Type	Texture	Very Low	Low	Medium	High	Very High
				ppm		
Alluvial	clay, silty clay	<114	114 - 182	183 - 227	228 - 273	>273
	clay loam, silty clay loam	<91	91 - 136	137 - 182	183 - 205	>205
	loam and silt loam	<57	57 - 91	92 - 136	137 - 159	>159
	sandy loam	<45	45 - 80	81 - 114	115 - 136	>136
Upland	clay, silty clay	<114	114 - 182	183 - 227	228 - 250	>250
	clay loam, silty clay loam	<57	57 - 102	103 - 148	149 - 170	>170
	loam and silt loam	<57	57 - 91	92 - 136	137 - 159	>159
	sandy loam	<45	45 - 80	81 - 114	115 - 136	>136
Fertilizer Recommendation				lb K_2O / Acre		
		60	40	20	0	0

Table 3-3. Zinc (Zn) fertilizer recommendations for rice grown on Louisiana soils based on the Mehlich 3 soil test.

Soil Test	≤ 1 ppm		1 - 1.5 ppm			1.6 - 2 ppm	
pH	≥ 7	< 7	≥ 7	6.9 - 6.0	< 6	≥ 7	< 7
Granular fertilizer recommendation	15 lb/A	10 lb/A	10 lb/A	5 lb/A‡	none	5 lb/A	none

† The granular zinc fertilizer source must be at least 50percent water soluble or higher rates of zinc may be needed.

‡ Even distribution of most granular zinc fertilizer sources at rates of less than 10 lbs/A is difficult to achieve however, it can be achieved when the zinc is premixed with a starter N application using 50 -100 lbs. ammonium sulfate.

Table 3-4. Sulfur (S) fertilizer recommendations for rice grown on Louisiana soils based on the Mehlich 3 soil test.

Soil Test Level	Soil test Results	Fertilizer Recommendation
	ppm	lb S per acre
Low	<12	20 - 25*
Medium	12 - 16	5 - 15
High	>16	none

*Application of 100 pounds of ammonium sulfate will provide 21 lb N and 24 lb S.

Salinity in Rice Soils

Salinity is a measure of the amount of soluble salts in soil or water. A soluble salt is any compound that dissolves in water. Many salts can be found in soils, some of the more common salts are: calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^{+}), sodium (Na^{+}), chloride (Cl^{-}), sulfate (SO_4^{-2}), carbonate (CO_3^{-}) and nitrate (NO_3^{-}). Not all salts are bad. Some fertilizers are salts and are necessary for healthy plant growth and development. Some salts, including both sodium and chloride, can become toxic when taken up at high levels.

Soils that accumulate high levels of sodium salts as a result of irrigation or coastal flooding are classified as saline, sodic or saline-sodic. Saline soils have a high concentration of total soluble salts. Sodic soils, on the other hand, have a high concentration of sodium (Na^{+}). Saline-sodic soils include both problems. The procedure described in this guide actually estimates total dissolved solids (TDS), or soluble salts, and is a measure of potential soil salinity problems. To measure potential sodic (sodium) soil problems requires more elaborate laboratory procedures and analytical equipment.

Salt Level, ppm	Interpretation
0 – 300	Very low
301 – 600	Low
601 – 1000	Medium
1001 – 1500	High
>1500	Very high

At very low salt levels, few if any crops will be damaged. At low levels, very sensitive crops may be damaged. The danger of salt damage increases if plants are very young or the soil becomes very dry.

Salt in the soil can be either precipitated on soil surfaces or dissolved in the soil solution. The soil solution occupies the spaces between the solid soil particles. When it completely fills these spaces, the soil is saturated. To measure soil salinity all soluble salts must be dissolved; this is done by mixing the soil with water in specific amounts followed by separating the soil solids from the solution and analyzing the TDS in the solution.

Most meters used to measure salinity in water actually measure electrical conductivity (EC). The more salt the water contains the easier it is for electricity to flow through it. Higher salt content means a higher EC.

Electrical conductivity may be expressed several ways which sometimes causes confusion. It can be expressed as millimhos per centimeter (mmhos/cm), or millisiemens per centimeter (mS/cm) or decisiemens per meter (dS/m). All of these units are equivalent and express the ability of a solution to conduct electricity over a specific distance.

Soil salinity readings depend upon the relative amounts of soil and water added during analysis. This is another major source of confusion as some laboratories report results of 1 part soil to 2 parts water ($EC_{1:2}$). Others report results on a saturated paste basis (EC_{se}), the standard used in scientific literature to establish plant tolerances to salt. For the same soil sample, $EC_{1:2}$ values are about half those of EC_{se}. The LSU AgCenter's Soil and Plant Testing Lab reports salinity values on an EC_{se} basis.

To make interpretation easier, especially if measurements from different sources are to be compared, it is easier to convert them to parts per million (ppm). Some meters already have a scale that takes this into account and is expressed in ppm. To convert EC to ppm, multiply EC_{se} by 640 (or $EC_{1:2}$ by 1280) if the EC<5 or by 800 (EC1:2 by 1600) if EC>5. 1 mmhos/cm = 1 mS/cm = 1 dS/m = 640 ppm (or 800 if EC>5). This is not an exact conversion, but will work in this case.

EC readings and expected crop responses.

Salinity, EC	Crop Responses
0 – 2	Mostly negligible
2 – 4	Yields affected in very sensitive crops
4 – 8	Yields affected in many crops
8 – 16	Only tolerant crops unaffected
>16	Only very tolerant crops unaffected

A few of the crops grown in Louisiana and their respective salt tolerance ratings (as seedlings) are shown below.

Crop	EC	ppm	Rating
Rice	3.0	1,920	S
Sugarcane	1.7	1,088	MS
Sorghum	6.8	4,352	MT
Soybeans	5.0	3,200	MT
Wheat	6.0	3,840	MT
Bermudagrass	6.9	3,840	T
Ryegrass	5.6	2,584	MT

Source: USDA-ARS salinity lab
Seedling stages are generally less tolerant than older stages.

Measuring salinity or EC alone will provide information on potential soil salinity problems. However, it does not provide a complete picture of soil sodicity (Na+). The ratio of the amount of exchangeable sodium to the amount of exchangeable calcium plus magnesium is often used to predict the potential of sodic (Na+) soil problems. This is called the sodium absorption ratio (SAR). A combination of EC and SAR is a better measure of the likelihood of both saline and sodic soil problems. The table below was developed by LSU AgCenter scientists to better interpret the effects of salt water on land to be used for rice production.

	Salts (ppm)		SAR	Effects
None	<500	And	<4	No effect on yield
Mild	500 – 1000	Or	<4	Little to no effect on yield
Moderate	1000 – 2000	Or	<6	Some yield reduction possible
Severe	2000 – 6000	Or	<13	Substantial yield reduction w/0 remediation
Very Severe	>6000	Or	>13	Catastrophic crop failure

Using Salt Water to Irrigate Rice

Salt water can become a problem in rice production, especially in some areas in dry years. A small amount of salt water is not dangerous to rice at any stage of growth. Higher concentrations affect the existing crop and can cause a build-up of salt in the soil.

Rice grown on soils relatively free of salt is tolerant to salt water with 35 grains (600 parts per million) per gallon of sodium chloride. One flooding of 6 acre inches of water containing 35 grains (600 p.p.m.) of salt would leave 800 pounds of salt per acre in the surface soil. Three such floodings would leave 2400 pounds per acre, which is about all the crop would endure. Continued use of even this mount of salt will lead to trouble. Water containing more than 35 grains per gallon (600 p.p.m.) cannot be used continuously through the growing season and year after year without injury to both crop and soil.

Where sodium chloride or sodium carbonate has accumulated in the soil, less than 1000 p.p.m. is not toxic to germination if there is normal soil moisture.

The following table can be used as a guide for tolerance of rice to salt water.

Commonly Accepted Tolerance of Rice to Salt Water

Concentrations of Salt as NaCl in water		
Grains per Gallon	p.p.m.	Stage of Growth
35	600	Tolerable at all stages, not harmful
75	1300	Rarely harmful and only to seedlings after soil is dry enough to crack. Tolerable from tillering on to heading
100	1700	Harmful before tillering, tolerable from jointing to heading
200	3400	Harmful before booting, tolerable from booting to heading
300	5100	Harmful to all stages of growth. This concentration stops growth and can only be used at the heading stage when soil is saturated with fresh water.

This information was taken from material compiled by Dr. M. B. Sturgis, head, L.S.U. Department of Agronomy and Mr. Lewis Hill former extension rice specialist.

Poultry Litter use in Louisiana Rice Production

A loss of production on recently precision-leveled rice fields and rice following crawfish in a rice-crawfish-rice rotation has become a common occurrence in commercial Louisiana rice production. This is especially true on mechanically altered silt loam soils of the coastal plains found in Southwest Louisiana. The

Fig. 3-7. Common commercial poultry litter.

use of poultry litter on unproductive areas has provided an increase in productivity to levels above those realized prior to precision leveling in many cases. It has also been reported that the use of litter in conjunction with inorganic fertilizers provides improved yields above those found when using inorganic fertilizers alone.

Poultry litter is made up of the bedding material and manure from birds used in a commercial poultry facility. The most common litter material available in Louisiana is obtained from commercial broiler houses. The most common bedding materials used in commercial broiler houses include wood shavings, rice hulls and sawdust (Fig. 3-7). As the bedding material is used it forms a hard layer on the surface often referred to as a cake. This cake can be removed (decaked) after one flock has been grown or can be removed after several flocks have been grown depending on the management practices of the producer. Therefore, nutritive value of litter is not constant between sources. The nutrient content can vary considerably depending on the bedding material used, number of flocks grown between decaking, feed source and feed efficiency, bird type, management practices and whether or not the litter has been composted or is fresh. This variability makes it imperative that every delivered batch of litter be tested to determine the nutrient and water content.

Nutrient Content

Poultry litter contains nitrogen (N), phosphorus (P) and potassium (K), as well as several micronutrients and organic acids. Poultry litter on average contains N-P_2O_5-K_2O at a concentration around 60 pounds of each nutrient per ton of material on a dry basis. However, the actual content varies greatly between batches and must always be analyzed prior to determining an application rate.

There are multiple organic and inorganic forms of N contained in poultry litter. Rice takes up the inorganic forms of N including NH_4^+ and NO_3^- during the growth and development of the crop. Initially, the inorganic N content is only 10% or less of the total N content in the litter. Some of the inorganic N is mineralized during the first year and made available for uptake by rice. However, once the rice crop is flooded and the soil converts to an anaerobic (without oxygen) condition, NO_3-N quickly is lost due do to denitrification and will no longer be available for uptake by rice. This is one of the reasons that N use efficiency of poultry litter by rice is less efficient as compared to that of upland crops. Past research has shown the pre-flood urea-N equivalence for rice ranges from 25 - 41% of the N content of the poultry litter. Therefore, a conservative estimate is that 25% of the N contained in the poultry litter will count towards the normal recommended preflood N rate for a particular rice cultivar and the rate of applied urea should be reduced to represent the litter N contribution. These estimates were developed from poultry litter applied the same day that rice was drill seeded. Application of litter several weeks before planting may further reduce N availability for drill-seeded rice. Research has not evaluated the urea-N equivalence of litter in water-seeded systems. However, it is expected that the urea equivalence of litter in a water-seeded system would be slightly greater than that of a drill-seeded, delayed flood production system since the litter would be in a saturated anaerobic condition at an earlier point in the season, which would limit the nitrification and subsequent denitrification of mineralized NH_4-N.

Total P_2O_5 and K_2O concentrations of litter are often very close in concentration to that of total N. Like N, the total P and K found in litter is made up of both organic and inorganic forms. The alternating flooded and draining (flushing) associated with early-season, drill-seeded rice management and the establishment of the permanent flood tends to accelerate the mineralization of organic bound nutrients into inorganic, plant available forms. Research comparing the uptake efficiency of P and K by rice between inorganic fertilizers and poultry litter when applied at equal concentrations of P_2O_5 and K_2O has shown that the P and K applied from poultry litter is an equivalent source of these nutrients. Therefore, 100% of the P and K found in poultry litter can be applied towards the needs of the rice crop during the first year for a drill-seeded, delayed flood rice production system.

The P needs of rice are less than the N needs. It is estimated that a 7000 lb/A (43 barrels) rice yield will remove approximately 112, 60 and 168 lb of N, P_2O_5 and K_2O from the soil, respectively. If poultry litter is applied based on the N needs of rice an over application of P will occur. The surplus P will buildup soil test P to excessive levels with repeated applications over several years and has the potential to cause environmental problems. This excess P can be lost through run-off from fields can contribute to eutrophication of nearby surface waters. This is a problem often seen in pastures grown for forage in areas near poultry facilities where poultry litter has been used repeatedly in this fashion. Therefore, it is important that poultry litter only be applied based on the P needs of the rice crop as indicated from a current soil test.

Litter Sampling

Litter is generally delivered by 18-wheelers to field edges and stacked into piles prior to spreading (Fig. 3-8). Physical and chemical variability of poultry litter between delivered batches are not uncommon (Fig. 3-9). It is important to sample each delivered source to account for this variability. When sampling poultry litter for nutrient analysis, it is best to take multiple samples from all depths and sides of the litter pile. The samples can then be physically combined to create one composite sample. The composite sample will improve chemical analysis and will be more representative of the litter as a whole. Litter samples are generally analyzed on a wet, as is basis. Samples taken only from one location of the litter pile can alter analysis results. For example, litter stacked in the field waiting to be applied is often rained on prior to spreading. Simply taking a surface sample of the litter may result in a sample that has an elevated water content as compared with the litter pile as a whole. This, in turn, will subsequently alter the N, P_2O_5 and K_2O concentration of the litter. In cases where it is known that the litter will be stored for long periods of time before spreading, samples can be taken immediately after delivery to the field when the litter is the driest. Although, litter samples are generally analyzed on a moist basis, the results may be reported on a wet or dry basis depending on the laboratory used.

Fig. 3-8. Litter delivered by 18-wheelers to field edges.

Fig. 3-9. Litter piles prior to spreading.

Litter Sources

Poultry litter can be purchased on a fresh, composted or in a pelletized form. The pelletized form is generally more expensive per unit of nutrient, has equivalent nutrient levels, and has lower water content. The pelletized form does improve handling, field application and equipment clean-up. Research has shown that nutrient availability between fresh, composted and pelletized litter is equivalent between the sources when applied at similar N, P_2O_5 and K_2O levels. The ease of use of the pelletized litter must be weighed against the increase in cost when making a litter source selection.

General Recommendations

The use efficiency of nutrients in poultry litter is maximized when the litter is applied and incorporated immediately prior to drill seeding. An evaluation of the time of application of poultry litter indicated that the N-uptake by rice was reduced by 16% when the litter was applied 10 days prior to seeding as compared with application immediately prior to seeding. The urea-N equivalence of the litter during this study was 41%. Other yield based research has also shown that litter applied in the fall results in lower yields as compared with litter applied in the spring prior to seeding. While not as efficient, litter can be surface applied in a reduced tillage system. Due to the alkaline nature of poultry litter, volatilization losses can be excessive on surface applied litter. Surface losses of P and K can also be expected from run-off events associated with field flushing.

Other general observations of the use of poultry litter in a rice production system include:

- The responses of litter applied on precision leveled clay soils are generally not as great as compared with precision leveled silt loam soils.
- Consultants and producers have noted that even distribution of litter at rates less than one ton per acre are difficult. The cake and clods of the litter and the use of poor application equipment are the main culprits of the distribution problem. For this reason, rates of less than one ton are rarely used. The use of properly calibrated spreading equipment in good operating condition should always be used to maximize even distribution.
- Producers and consultants have also noted an increase in weed seed germination as a result of the use of poultry litter. While not substantiated, the increase of weed incidence seen when using poultry litter is most likely a derivative of the organic acids enhancing weed germination and the additional nutrients enhancing weed growth. It is highly unlikely that the increased weed pressure is caused by weed seed being introduced by the litter itself.
- Continued use of litter can increase organic matter, soil structure and CEC. However, a significant increase in these soil properties should not be expected from onetime or sporadic use.

Best Management Guidelines for the Use of Poultry Litter

1. Obtain a soil test on precision leveled and problem areas of fields separate from productive areas.
2. Obtain a composite poultry litter sample and send off for N-P-K and water content analysis. Generally 1-2 weeks are needed for chemical analysis.
3. Determine litter rate based on P_2O_5 recommendations provided by a soil test.
4. Determine supplemental K needs, if any, based on soil test results.
5. Apply poultry litter and K as close to planting as possible using calibrated equipment and incorporate.
6. Determine supplemental preflood N needs based on a 25% urea equivalence.
7. Resample precision leveled and problem areas in subsequent years to monitor nutrient changes.

Example of Poultry Litter Rate Determinations

A soil test of a precision leveled area indicated that 40 lb of P_2O_5 and 60 lb of K_2O are required to grow a rice crop. Poultry litter analysis indicated that the litter contains 2.5 percent N, 3.2 percent P_2O_5, 2.7 percent K_2O and 40 percent moisture. Litter analysis is reported on an "as is" wet basis.

1. Determine how much total litter will be needed to supply 40 lb of P_2O_5. Calculate nutrients based on dry basis first then adjust to wet (as applied) basis.
   a. Divide total lb needed by percent P_2O_5 in litter.
      i. 40 lb P_2O_5 divided by 3.2 percent = 40/0.032 = 1250
   b. Convert to as applied (wet) basis.
      i. Need 1250 lb dry
      ii. Litter is 40 percent water
      iii. 100 percent - 40 percent = 60 percent dry matter
      iv. 1250 lb dry litter / 0.60 dry matter = 2083 lb as is (wet) litter needed
2. Determine how much additional K from potash is needed.
   a. Determine amount of K_2O supplied by litter
      i. 2083 lb (wet) applied * 0.60 dry matter = 1250 lb dry litter
      ii. Litter contains 2.7 percent K_2O
      iii. 2.7 percent of 1250 lb = 0.027 * 1250 = 33.7 lb K_2O
   b. Determine additional K_2O needed from potash (0-0-60). A total of 60 lb K_2O is needed based on the soil test.
      i. 60 lb needed – 33.7 lb supplied by litter = 26.3 lb K_2O needed
   c. Determine potash rate
      i. K_2O fertilizer (0-0-60) is 60 percent K_2O
      ii. 26.3 lb K_2O needed / 0.60 lb K_2O per lb of 0-0-60 = 43.8 lb of 0-0-60
3. Determine how much preflood N is supplied by litter and how much additional urea is needed based on a 90 lb/A preflood N rate.
   a. Determine N supplied by litter. Assume that the litter will provide a 25 percent urea equivalent.
      i. 2083 lb (wet) applied * 0.60 dry matter = 1250 lb dry litter
      ii. Litter contains 2.5 percent Nitrogen
      iii. 2.5 percent of 1250 lb = 0.025* 1250 = 31.2 lb of N
      iv. N in litter is only 25 percent of the value of urea
      v. 25 percent of 31.2 = 0.025 N in litter * 0.25 urea equivalent = 7.8 lb N supplied by litter
   b. Determine additional preflood N needed.
      i. 90 lb needed - 7.8 lb N supplied = 82.2 lb N needed
   c. Convert to lb of urea
      i. Urea (46-0-0) is 46 percent N
      ii. 82.2 lb N / 0.46 = 178.7 lb urea needed to supply 82.2 lb nitrogen

Poultry litter from different sources can contain differing amounts of N, P_2O_5 and K_2O. It is important to individually test each poultry litter load.

Chapter 4

Rice Growth and Development

Richard Dunand and Johnny Saichuk

First (Main) Crop

Growth and development of the rice plant involve continuous change. This means important growth events occur in the rice plant at all times. Therefore, the overall daily health of the rice plant is important. If the plant is unhealthy during any state of growth, the overall growth, development and grain yield of the plant are limited. It is important to understand the growth and development of the plant.

The ability to identify growth stages is important for proper management of the rice crop. Because management practices are tied to the growth and development of the rice plant, an understanding of the growth of rice is essential for management of a healthy crop. Timing of agronomic practices associated with water management, fertility, pest control and plant growth regulation is the most important aspect of rice management. Understanding the growth and development of the rice plant enables the grower to properly time recommended practices.

Growth and Development

Growth and development of rice grown as an annual from seed begin with the germination of seed and ends with the formation of grain. During that period, growth and development of the rice plant can be divided into two phases: vegetative and reproductive. These two phases deal with growth and development of different plant parts. It is important to remember growth and development of rice are a continuous process rather than a series of distinct events. They are discussed as separate events for convenience.

The vegetative phase deals primarily with the growth and development of the plant from germination to the beginning of panicle development inside the main stem. The reproductive phase deals mainly with the growth and development of the plant from the end of the vegetative phase to grain maturity. Both phases are important in the life of the rice plant. They complement each other to produce a plant that can absorb sunlight and convert that energy into food in the form of grain.

The vegetative and reproductive phases of growth are subdivided into groups of growth stages. In the vegetative phase of growth there are four stages: (1) emergence, (2) seedling development, (3) tillering and (4) internode elongation. Similarly, the reproductive phase of growth is subdivided into five stages: (1) prebooting, (2) booting, (3) heading, (4) grain filling and (5) maturity.

Growth Stages in the Vegetative Phase

Emergence

When the seed is exposed to moisture, oxygen and temperatures above 50 degrees F, the process of germination begins. The seed is mostly carbohydrates stored in the tissue called the endosperm. The embryo makes up most of the rest of the seed. Germination begins with imbibition of water. The seed swells, gains weight, conversion of carbohydrates to sugars begins and the embryo is activated.

Nutrition from the endosperm can supply the growing embryo for about 3 weeks. In the embryo, two primary structures grow and elongate: the radicle (first root) and coleoptile (protective covering enveloping the shoot). As the radicle and coleoptile grow, they apply pressure to the inside of the hull. Eventually, the hull weakens under the pressure, and the pointed, slender radicle and coleoptile emerge. Appearance of the radicle and coleoptile loosely defines the completion of germination.

After germination, the radicle and coleoptile continue to grow and develop primarily by elongation (or lengthening) (Fig. 4-1). The coleoptile elongates until

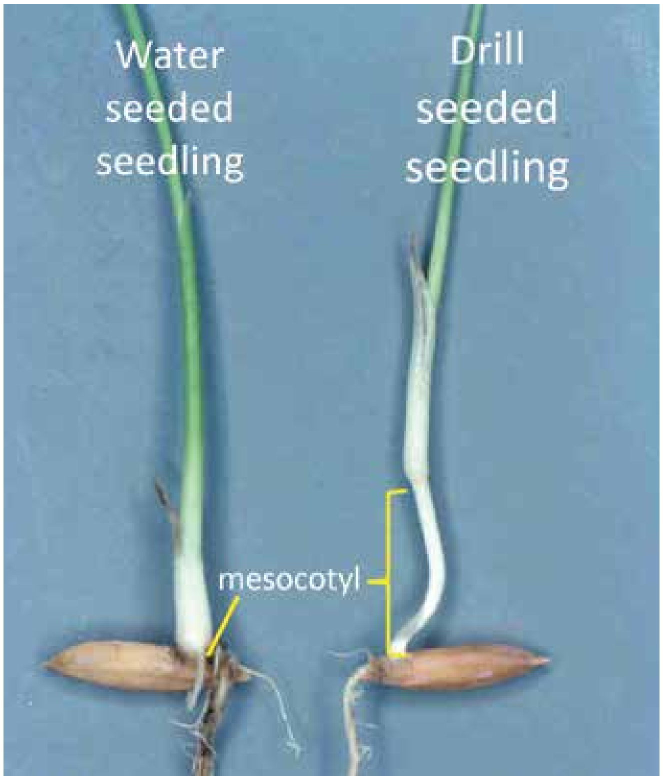


Fig. 4-1. Left, water-seeded seedling. Right, drill-seeded seedling.

it encounters light. If further elongation is required (for example, if the seeds are planted or covered too deeply), the region of the shoot below the coleoptile begins to elongate. This region is called the mesocotyl. Usually, it does not develop in water-seeded rice. The mesocotyl originates from the embryo area and merges with the coleoptile. The mesocotyl and coleoptile can elongate at the same time. They are sometimes difficult to tell apart. Usually, the mesocotyl is white, and the coleoptile is off-white and slightly yellowish. Shortly after the coleoptile is exposed to light, usually at the soil surface, it stops elongation. The appearance of the coleoptile signals emergence. From a production perspective (and in the DD50 program), emergence is called when 8 to 10 seedlings 3/4 inch tall are visible per square foot in water-seeded rice or 4 to 7 plants per foot for drill-seeded rice, depending on drill spacing (Fig. 4-2)

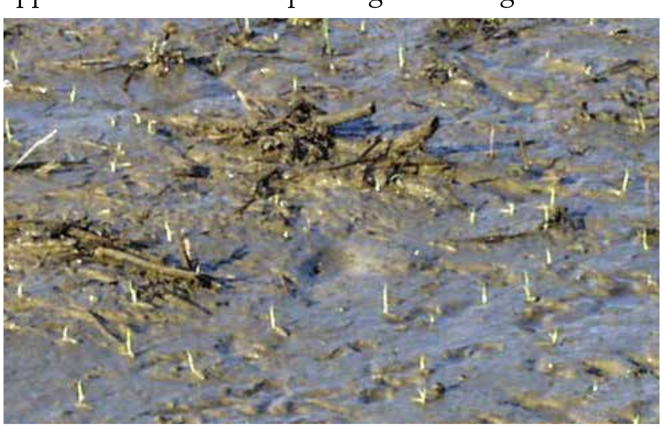


Fig. 4-2. Emergence, water-seeded rice.

Seedling Development

Seedling development begins when the primary leaf appears shortly after the coleoptile is exposed to light and splits open at the end. The primary leaf elongates through and above the coleoptile (Fig. 4-3). The primary leaf is not a typical leaf blade and is usually 1 inch or less in length. The primary leaf acts as a protective covering for the next developing leaf. As the seedling grows, the next leaf elongates through and past the tip of the primary leaf. Continuing to grow and develop, the leaf differentiates into three distinct parts: the sheath, collar and blade (Fig. 4-4). A leaf that is differentiated into a sheath, collar and blade is considered complete; thus, the first leaf to develop after the primary leaf is the first complete leaf. The

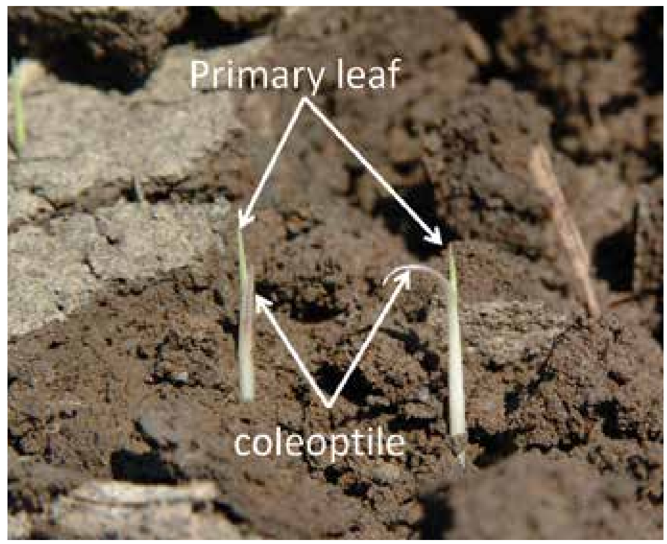


Fig. 4-3. Emergence, drill seeded rice.

Fig. 4-4. One leaf seedling.

one-leaf stage of growth rice has a primary leaf and a completely developed leaf.

All subsequent leaves after the first leaf are complete leaves. The sheath is the bottom-most part of a complete leaf. Initially, all leaves appear to originate from a common point. The area is actually a compressed stem with each leaf originating from a separate node. Throughout the vegetative growth period, there is no true stem (culm) development. The stem of rice, as with all grasses, is called the culm. Leaf blades are held up by the tightly wrapped leaf sheaths. This provides support much like tightly rolling up several sheets of paper to form a column. Without this mechanism, the leaves would lay flat on the soil surface.

The collar is the part of the leaf where the sheath and blade join (Fig. 4-5). It is composed of strong cells that form a semicircle that clasps the leaf sheath during vegetative development and the stem during reproductive development. It is marked by the presence of membranous tissue on its inner surface called the ligule. Rice also has two slender, hairy structures on each end of the collar called auricles.

The blade or lamina is the part of the leaf where most photosynthesis occurs. Photosynthesis is the process by which plants in the presence of light and chlorophyll convert sunlight, water and carbon dioxide into glucose (a sugar), water and oxygen. It contains more chlorophyll than any other part of the leaf. Chlorophyll is the green pigment in leaves that absorbs sunlight. The absence of chlorophyll is called chlorosis. The blade is the first part of a complete leaf to appear as a leaf grows and develops. It is followed in order by the appearance of the collar at the base of the blade then the sheath below the collar. During the vegetative phase of growth, the collar and blade of each complete leaf become fully visible. Only the oldest leaf sheath is completely visible, since the younger leaf sheaths remain covered by sheaths of leaves whose development preceded them. Each new leaf originates from within the previous leaf so that the oldest leaves are both the outermost leaves and have the lowest point of origin.

Since growth and development are continuous, by the time the first complete leaf blade has expanded, the tip of the second complete leaf blade is usually already protruding through the top of the sheath of the first complete leaf. The second leaf grows and develops in the same manner as the first. When the second collar is visible above the collar of the first leaf, it is called two- leaf rice (Fig. 4-6). Subsequent leaves develop in the same manner, with the number of fully developed leaves being used to describe the seedling stage of growth.

Fig. 4-5. Collar of rice leaf.

Fig. 4-6. Two leaf seedlings.

When the second complete leaf matures, the sheath and blade are each longer and wider than their counterparts on the first complete leaf. This trend is noted for each subsequent leaf until about the ninth complete leaf, after which leaf size either remains constant or decreases. Although a rice plant can produce many (about 15) leaves, as new leaves are produced, older leaves senesce (die and drop off), resulting in a somewhat constant four to five green leaves per shoot at nearly all times in the life of the plant. Each additional leaf develops higher on the shoot and on the opposite side of the previous leaf producing an arrangement referred to as alternate, two-ranked and in a single plane. Seedling growth continues in this manner through the third to fourth leaf, clearly denoting plant establishment.

Root system development is simultaneous to shoot development. In addition to the radicle, other fibrous roots develop from the seed area and, with the radicle, form the primary root system (Fig. 4-7). The primary root system grows into a shallow, highly branched mass limited in its growth to the immediate environment of the seed. The primary root system is temporary, serving mainly to provide nutrients and moisture to the emerging plant and young seedling. In contrast, the secondary root system is more permanent and originates from the base of the coleoptile.

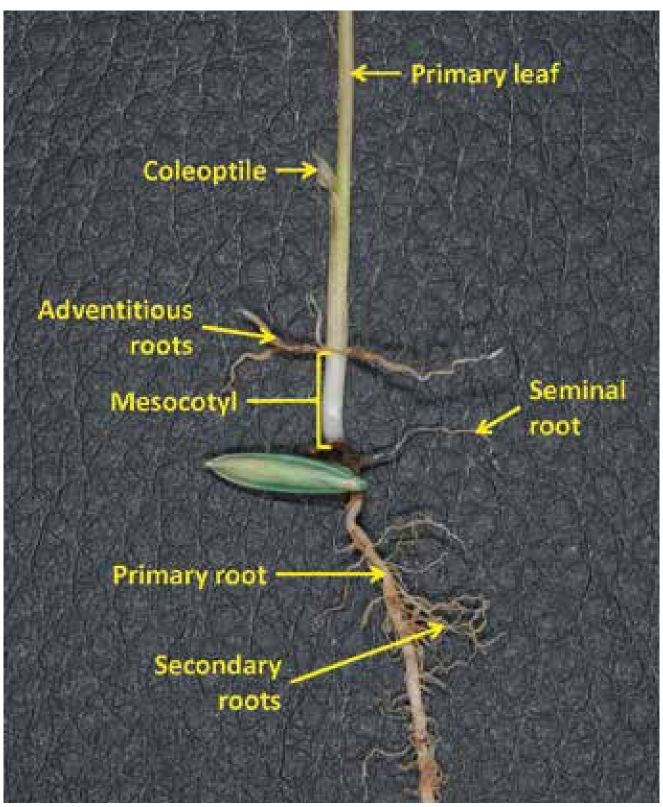


Fig. 4-7. Rice seedling root system.

In water-seeded rice (or any time seeds are left on the soil surface), the primary and secondary root systems appear to originate from a common point. When seed are covered with soil as in drill seeding, the primary root system originates at or near the seed, while the secondary root system starts in a zone above the seed originating from the base of the coleoptile. These differences can have an impact on some management practices.

During the seedling stages, the secondary root system, composed of adventitious roots, is not highly developed and appears primarily as several nonbranched roots spreading in all directions from the base of the coleoptile in a plane roughly parallel to the soil surface. The secondary root system provides the bulk of the water and nutrient requirements of the plant for the remainder of the vegetative phase and into the reproductive phase.

During the seedling stages, the plant has clearly defined shoot and root parts. Above the soil surface, the shoot is composed of one or more completely developed leaves at the base of which are the primary leaf and upper portions of the coleoptile. Below the soil surface, the root system is composed of the primary root system originating from the seed and the secondary root system originating from the base of the coleoptile. Plants originating from seed placed deep below the soil surface will have extensive mesocotyl and coleoptile elongation compared with plants originating from seed placed on or near the soil surface (Fig. 4-1). Seed placement on the soil surface usually results in no mesocotyl development and little coleoptile elongation. In general, the presence of primary and secondary roots and a shoot, which consists of leaf parts from several leaves, is the basic structure of the rice plant during the seedling stages of growth.

Tillering

Tillers (stools) first appear as the tips of leaf blades emerging from the tops of sheaths of completely developed leaves on the main shoot. This gives the appearance of a complete leaf that is producing more than one blade (Fig. 4-8). This occurs because tillers originate inside the sheath of a leaf just above the point where the sheath attaches at the base of the plant. If the leaf sheath is removed, the bud of a beginning tiller will appear as a small green triangular growth at the base of the leaf. This bud is called an axillary bud. Tillers that originate on the main shoot in this manner are primary tillers. When the first complete leaf of the first primary tiller is visually fully differentiated (blade, collar and sheath apparent), the seedling is in the first tiller stage of growth.

The first primary tiller usually emerges from the sheath of the first complete leaf before the fifth leaf. If a second tiller appears, it usually emerges from the sheath of the second complete leaf and so on. Consequently, tillers develop on the main shoot in an alternate fashion like the leaves. When the second primary tiller appears, it is called two-tiller rice. The appearance of tillers in this manner usually continues through about fourth or fifth primary tiller. If plant populations are very low (fewer than 10 plants per square foot), tillers may originate from primary tillers much in the same manner as primary tillers originate from the main shoot. Tillers originating from primary tillers are considered secondary tillers. When this occurs, the stage of growth of the plant is secondary tillering.

Fig. 4-8. One tiller rice seedling.

Tillers grow and develop in much the same manner as the main shoot, but they lag behind the main shoot in their development. This lag is directly related to the time a tiller first appears. It usually results in tillers producing fewer leaves and having less height and maturing slightly later than the main shoot.

During tillering (stooling), at the base of the main shoot, crown development becomes noticeable. The crown is the region of a plant where shoots and secondary roots join. Inside a crown, nodes form at the same time as the development of each leaf. The nodes appear as white bands about 1⁄16 inch thick and running across the crown, usually parallel with the soil surface. Initially, the plant tissue between nodes is solid, but with age, the tissue disintegrates, leaving a hollow cavity between nodes. With time, the nodes become separate and distinct, with spaces (internodes) about ¼ inch or less in length between them.

In addition to crown development, leaf and root development continue on the main shoot. An additional five to six complete leaves form with as many additional nodes forming above the older nodes in the main shoot crown. On the main shoot, some of the older leaves turn yellow and brown. The changes in color begin at the tip of a leaf blade and gradually move to the base. This process is called senescence. The lowest leaves senesce first with the process continuing from the bottom up or from oldest to youngest leaves. From this point on, there is simultaneous senescence of older leaves and production of new leaves. The result is that there are never more than four or five fully functional leaves on a shoot at one time.

In addition to changes in leaves, the main shoot crown area expands. Some of the older internodes at the base of the crown crowd together and become indiscernible by the unaided eye. Usually, no more than seven or eight crown internodes are clearly observable in a dissected crown. Sometimes, the uppermost internode in a crown elongates ½ to 1 inch. This can occur if depth of planting, depth of flood, plant population, N fertility and other factors that tend to promote elongation in rice are excessive. During tillering, tiller crowns develop. Along with growth of the main shoot and tiller shoot crowns, more secondary roots form, arising from the expanding surface of the crowns. These roots grow larger than those that formed during the seedling stages. They are wider and longer as they mature. A vegetatively mature rice plant will be composed of a fully developed main shoot, several tillers in varying degrees of maturity, healthy green leaves, yellow senescing leaves and an actively developing secondary root system.

Internode Elongation and Stem Development

Each stem or culm is composed of nodes and internodes. The node is the swollen area of the stem where the base of the leaf sheath is attached. It is also an area where a great deal of growth activity occurs. This area is one of several meristematic regions. Growth of the stem is the consequence of the production of new cells along with the increase in size, especially length, of these cells. The area between each node is the internode. The combination of node and internode is commonly called a "joint."

The formation and expansion of hollow internodes above a crown are the process that produces a stem, determines stem length and contributes to a marked increase in plant height. Internode formation above a crown begins with the formation of a stem node similar to that of the crown nodes (Fig. 4-9). The stem node forms above the uppermost crown node, and a stem internode begins to form between the two nodes. As the stem internode begins to form, chlorophyll accumulates in the tissue below the stem node. This produces green color in that tissue. Cutting the stem lengthwise usually reveals this chlorophyll accumulation as a band or ring. This is commonly called "green ring" and indicates the onset of internode elongation (Fig. 4-10). It also signals a change

Fig. 4-9. Plant with three distinct crown nodes and a fourth developing.

Fig. 4-10. Green ring-internode elongation.

Fig. 4-11. Half-inch internode.

in the plant from vegetative to the reproductive stage of development (Fig. 4-11).

Subsequent nodes and internodes develop above each other. Growth of the stem can be compared to the extension of a telescope with the basal sections extending first and the top last. As the newly formed nodes on the main stem become clearly separated by internodes, the stages of growth of the plant progress from first internode, to second internode, to third internode et cetera. With the formation and elongation of each stem internode, the length of the stem and the height of the plant increase. Internode elongation occurs in all stems. The main stem is usually the first to form an internode and is also the first stem in which internode formation ends. In tillers, internode formation lags behind the main stem and usually begins in the older tillers first.

During the internode formation stages, each newly formed internode on a stem is longer and slenderer than the preceding one. The first internode formed is the basal most internode. It is the shortest and thickest internode of a stem. The basal internode is located directly above the crown. Sometimes, if the uppermost crown internode is elongated, it can be confused with the first internode of the main stem. One difference between these two internodes is the presence of roots. Sometimes, especially late in the development of the plant, the node at the top of the uppermost crown internode will have secondary roots associated with it. The upper node of the first stem internode will usually have no roots at that time. If roots are present, they will be short and fibrous. The last or uppermost internode that forms is the longest and slenderest internode and is directly connected to the base of the panicle. The elongation of the uppermost internodes causes the panicle to be exserted from the sheath of the uppermost or “flag leaf.” This constitutes heading. This process is covered in detail in the booting and heading sections.

Internode length varies, depending on variety and management practices. In general, internode lengths vary from 1 inch (basal internode) to 10 (uppermost internode) inches in semidwarf varieties and from 2 inches to 15 inches in tall varieties. These values, as well as internode elongation in general, can be influenced by planting date, plant population, soil fertility, depth of flood, weed competition and so on.

The number of internodes that forms in the main stem is relatively constant for a variety. Varieties now being grown have five to six internodes above the crown in the main stem. In tillers, fewer internodes may form than in the main stem. The number is highly variable and depends on how much the tiller lags behind the main stem in growth and development.

The time between seeding and internode formation depends primarily on the maturity of the variety, which is normally controlled by heat unit exposure (see DD-50 Rice Management Program section). It also can be influenced by planting date, plant population, soil fertility, flood depth and weed competition. In general, varieties classified as very early season maturity (head 75 to 79 days after planting) reach first internode about 6 weeks after planting. Varieties classified as early season maturity (head 80 to 84 days after planting) reach first internode about 7 weeks after planting, and varieties classified as midseason maturity (head 85 to 90 days after planting) reach first internode about 8 weeks after planting.

The appearance of nodes above the crown marks a change in the role of the node as the point of origin of several plant parts. Before stem internode formation begins above the crown, all leaves, tillers and secondary roots formed during that time originate from crown nodes. But after internode formation begins above the crown, the stem nodes serve mainly as the point of origin of all subsequent leaves.

Because stem nodes become separated significantly by internode development, the leaves that originate at these nodes are more separate and distinct than leaves formed before internode formation. The separation of these leaves increases as the length of the internodes increases. More complete leaf structure does not become apparent until the last two leaves to form have all or most of all three parts (sheath, collar and blade) completely visible. In varieties now in use, no more than six new complete leaves are produced on the main shoot after stem internode elongation begins. The last of these leaves to form is the flag leaf. It is the uppermost leaf on a mature stem. The sheath of the flag leaf, the boot, encloses the panicle during the elongation of the last two internodes. Not only is the flag leaf the last formed and uppermost leaf on a mature stem, it is also considered to be the most important leaf because the products of photosynthesis from it are most responsible for grain development.

Root growth approaches a maximum as internode formation above the crown begins. At this time, the secondary root system has developed extensively in all directions below the crown and has become highly branched. Newly formed roots are white; older roots are brown and black. A matted root system forms in addition to the secondary root system. It is composed of fibrous roots, which interweave and form a mat of roots near the soil surface.

Tiller formation usually ceases and tiller senescence begins during internode elongation. With adequate soil fertility, more tillers are produced during tillering than will survive to maturity. Tiller senescence begins as the crown becomes fully differentiated and continues until the last internode forms above the crown of the main stem.

Tiller senescence can be recognized by the smaller size of a tiller in comparison to other tillers on a plant. It appears significantly shorter than other tillers, has fewer complete leaves and fails to have significant internode development above the crown. Eventually, most leaves on a senescing tiller lose coloration while most leaves on other tillers remain green. The leaves and stems of senescing tillers turn brown and gray and, in most instances, disappear before the plant reaches maturity.

Internode elongation signals the end of vegetative growth. As stem internodes develop, reproductive growth begins.

Growth Stages During the Reproductive Phase

Prebooting

Prebooting refers to the interval after the onset of internode elongation and before flag leaf formation is complete. During prebooting, the remaining leaves of the plant develop, internode elongation and stem formation continue, and panicle formation begins.

When cells first begin actively dividing in the growing point or apical meristem, the process is called panicle initiation (PI). This occurs during the fifth week before heading. Although it can be positively identified only by microscopic techniques, it is closely associated with certain vegetative stages of growth. The growth stages that coincide closely with PI differ depending on the maturity of a variety. In very early season varieties, PI and internode elongation (green ring) occur at about the same time. In early season varieties, PI and second internode elongation occur almost simultaneously, and in midseason varieties, PI and third internode elongation are closely concurrent.

About 7 to 10 days after the beginning of active cell division at the growing point, an immature panicle about ⅛ inch long and 1⁄16 inch in diameter can be seen. At this point, the panicle can be seen inside the stem, resembling a small tuft of fuzz. This is referred to as panicle differentiation (PD) or panicle 2-mm (Fig. 4-12). The panicle, although small, already has begun to differentiate into distinct parts. Under a microscope or good hand lens, the beginnings of panicle branches and florets are recognizable. As the panicle develops, structures differentiate into a main axis and panicle branches (Fig. 4-13). The growing points of these branches differentiate into florets. Florets form at the

Fig. 4-12. Immature panicle, PD or panicle 2-mm.

Fig. 4-13. Half inch panicle.

uppermost branches first and progress downward. Because there are several panicle branches, development of florets within the panicle as a whole overlaps. Florets at the tip of a lower branch might be more advanced in their development than florets near the base of an upper panicle branch.

From a management stand point, panicle length defines plant development during this phase. A fungicide label, for example, might prescribe its application "from a 2- to 4-inch panicle." By the time the panicle is about 4 inches long, individual florets can be easily recognized on the most mature panicle branches.

Booting

Booting is the period during which growth and development of a panicle and its constituent parts are completed inside the sheath of the flag leaf. The sheath of the flag leaf is the boot. Booting stages are classified according to visible development of the panicle without dissection. For convenience, it is divided into three stages: early, middle and late boot. It is based on the amount of flag leaf sheath exposed above the collar of the leaf from which it emerges, the penultimate (second to last) leaf. Early boot (Fig. 4-14) is recognized when the collar of the flag leaf first appears above the collar of the penultimate leaf on the main stem and lasts until the collar of the flag leaf is about 2 inches above the collar of the penultimate leaf. Middle boot occurs when the collar of the flag leaf is 2 to 5 inches above the collar of the penultimate leaf and late boot when the collar of the flag leaf is 5 or more inches above the collar of the penultimate leaf. By late boot, the increasing panicle development causes the boot to swell, giving rise to the term "swollen boot." The boot becomes spindle shaped; it is wider in the middle tapering to a smaller diameter at each end.

Heading

Heading refers to the extension of the panicle through the sheath of the flag leaf on the main stem. This process is brought about mainly by the gradual and continuous elongation of the uppermost internode. When elongation of the uppermost internode of a main stem pushes the panicle out of the sheath of the flag leaf exposing the tip of the panicle, that stem has headed. The uppermost internode continues to elongate, revealing more of the panicle above the sheath of the flag leaf. Once the uppermost internode completes elongation, the full length of the panicle and a portion of the uppermost internode are exposed above the collar of the flag leaf. This stem is now fully headed.

Fig. 4-14. Early boot, flag leaf first appears above collar.

The main stem of each plant heads before its tillers. In a field of rice, there is considerable variation in the heading stage of growth. For example, some main stems, as well as tillers of other plants, may be fully headed while other plants may have just begun to head. Some management practices are based on the percentage of headed plants within a field. This should not be confused with the degree to which a single panicle has emerged from the boot or with the number of completely headed stems. Fifty percent heading means half of the stems in a sample have a range from barely extended to completely exposed panicles. It is not the degree of exposure of each

Fig. 4-15. Open floret with floral parts showing.

panicle but the percentage of stems with any panicle exposure that is important.

Each floret or flower is enclosed by protective structures called the lemma and palea. These become the hulls of mature grain. These hulls protect the delicate reproductive structures. The female reproductive organ is the pistil. At the tip of the pistil are two purplish feathery structures called stigmas. They are visible when the hulls open during flowering. More obvious are the male or pollen-bearing stamens. Each rice floret has a single pistil and six stamens. Pollen is produced and stored in anthers, tiny sacks at the tip of each stamen.

As heading progresses, flowering begins. During the middle hours of the day, mature florets open, exposing both the stigmas and anthers to air (Fig. 4-15). Pollen is shed as the anthers dry, split open and spill the pollen. The pollen then is carried by wind to the stigmas of the same or nearby plants. Special cells of the pollen grain join special cells within the pistil, completing fertilization and initiating grain formation.

Grain Filling

During grain filling, florets on the main stem become immature grains of rice. Formation of grain results mainly from accumulation of carbohydrates in the pistils of the florets. The primary source of the carbohydrate is from photosynthesis occurring in the uppermost three to four leaves and the stem. The carbohydrate that accumulates in grain is stored in the form of starch. The starchy portion of the grain is the endosperm. Initially, the starch is white and milky in consistency. When this milky accumulation is first

Fig. 4-16. Milk stage.

Fig. 4-17. Soft dough stage.

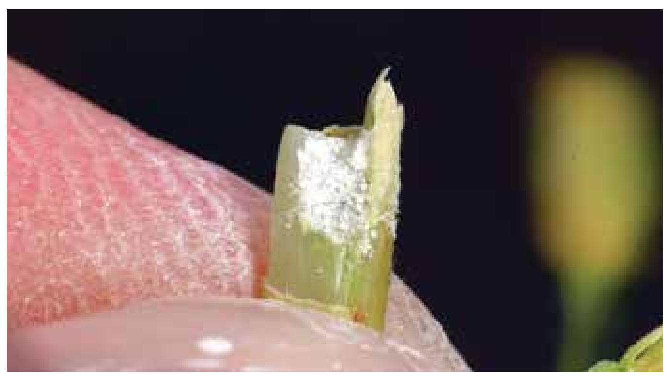


Fig. 4-18. Hard dough stage.

noticeable inside florets on the main stem, the stage is milk stage (Fig. 4-16).

Prior to pollination, the panicle in most varieties is green, relatively compact and erect. During milk stage, the accumulation of carbohydrate increases floret weight. Since the florets that accumulate carbohydrate first are located near the tip of the panicle, the panicle begins to lean and eventually will turn down. The milky consistency of the starch in the endosperm changes as it loses moisture. When the texture of the carbohydrate of the first florets pollinated on the main stem is like bread dough or firmer, this stage of growth is referred to as the dough stage (Fig. 4-17).

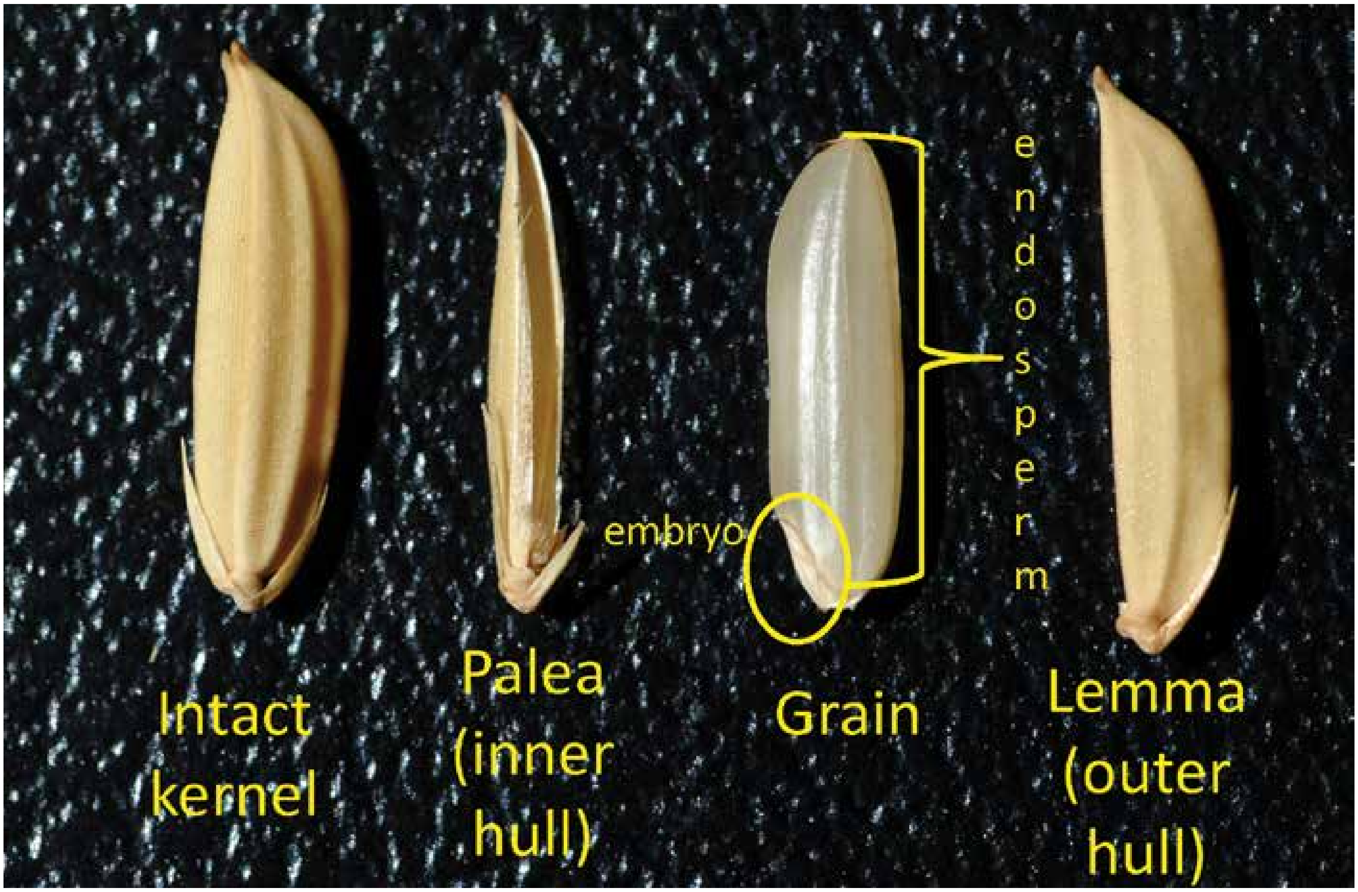


Fig. 4-19. Mature grain, intact and dissected.

As the carbohydrate in these florets continues to solidify during the dough stage, the endosperm becomes firm and has a chalky texture. Grains capable of being dented without breaking are in the soft dough stage. As more moisture is lost, grains become chalky and brittle. These grains are in the hard dough stage (Fig. 4-18).

During the grain filling stages, the florets develop and mature unevenly because pollination and subsequently grain filling occur unevenly. In the dough stage, only the florets on the main stem, which pollinated first, have an endosperm with the texture of bread dough. At the same time, the florets which pollinated later, including those on the tillers, may be in the milk stage. These are the last florets to accumulate carbohydrate. As more and more florets fill with carbohydrate, the translocation of carbohydrate to the panicle starts to decline, and the final phases of grain filling occur.

The panicle changes in color and form as the florets develop and mature. For most varieties of rice, the panicle changes from a uniform light green at the milk stage to a mixture of shades of brown and green during the dough stage. As the color changes so does the grain shape as a consequence of carbohydrate accumulation in the florets. The weight of the carbohydrate causes the panicle to bend over and the panicle branches to be less compact around the panicle axis. At the end of the grain filling stages, the panicle on the main culm has a bent and slightly open shape and is various shades of brown and green. The bent and slightly open configuration of the panicle remains unchanged from dough to maturity.

Maturity

Maturity occurs when carbohydrate is no longer translocated to the panicle. The moisture content of the grain is high after grain filling, and the primary process, which occurs in the panicle during the maturity stages, is the loss of moisture from the grain. The moisture content of the grain is used as the basis for judging degree of maturity. When the physiological

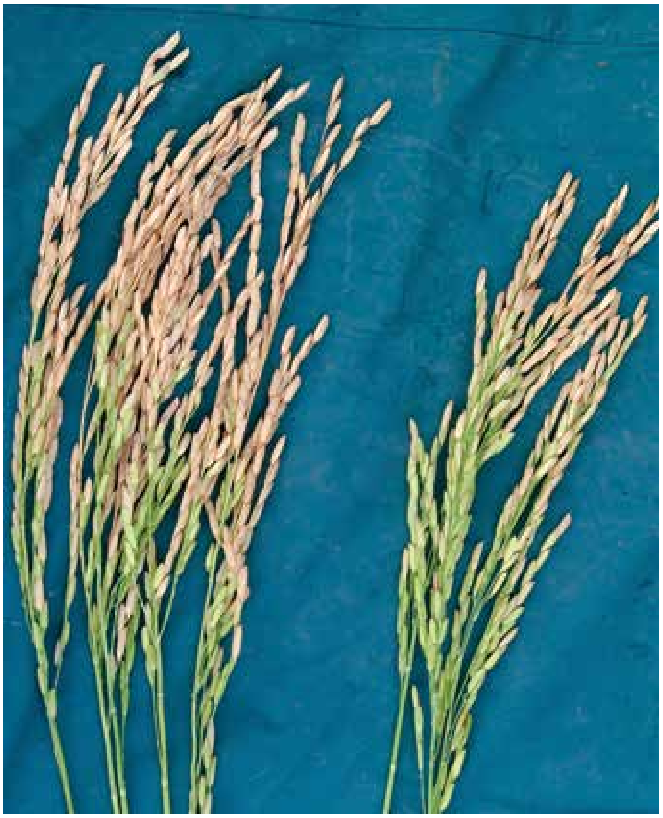


Fig. 4-20. Left panicles are two-thirds ripe. Right panicles are half ripe.

processes associated with grain filling cease and the collective moisture content of the grain on the main stem is 25 to 30%, the plant has reached physiological maturity (Fig. 4-19).

At this time, the endosperm of all grains on the panicle of a main stem is firm. Most grains are some shade of brown and the grains in the lower quarter of the panicle are the only ones with a greenish tint (Fig. 4-20). As maturity progresses and moisture is lost, the greenish tint of the hulls fades and the endosperm of all grains becomes uniformly hard and translucent. Once the average moisture content of the grains on the main stem is 15 to 18% (crop grain moisture, 18 to 21%), the plant has reached harvest maturity.

Second (Ratoon) Crop

Second crop stems originate from small axillary buds at the crown and stem nodes of the stubble remaining after harvest of the first crop (Fig. 4-21). At each node just above the area of attachment of the leaf sheath to the stem is a bud called an axillary bud.

Fig. 4-21. Axillary bud on stem.

Fig. 4-22. Crown or axillary buds at base of stem.

The leaf sheath is wrapped around the stem keeping it hidden unless the leaf itself is damaged or the bud begins to grow. As long as the apical bud, the one that eventually becomes the panicle, remains intact, axillary buds are suppressed. Removal of the panicle through harvesting or injury removes the suppressive effect, called apical dominance, permitting axillary buds to grow. In the crown, buds are difficult to detect (Fig. 4-22). At the stem nodes on first crop stubble they appear as a small (⅛ inch), mostly white, fleshy, triangular shaped structure. Buds that appear necrotic (have dark or dead tissue) and are associated with nodes that also appear necrotic usually do not develop into second crop growth.

There is one bud per node. Because each bud is associated with a single leaf, bud development on a stem follows the same pattern of leaf development.

Depending on stubble height, as many as three nodes can be on a stem of stubble with the potential to produce second crop growth. Once a bud on a stem above the crown develops, it usually inhibits the development of other similar buds. Buds on the crown usually are not suppressed. Five to six shoots can appear from the crown of a single plant. Second crop panicles can be produced from both axillary stem buds and from the crown. Shoots and stems originating from the crown usually produce larger panicles with higher quality grain than those originating from axillary buds on the stem; however, panicles originating from the crown mature later than those originating from axillary buds.

These buds are easily observed by pulling back the leaf sheath from the stem. This is particularly true of buds located at stem nodes. As axillary buds grow, they elongate within the cover of sheaths of first crop leaves. Depending on the node and integrity of the attached sheath, buds can elongate several inches before emerging from the sheaths. Once a developing bud senses sunlight, it differentiates into a green leaf. Leaf formation can occur before ratoon growth emerges from a first crop leaf sheath.

Second crop growth first appears as leaves originating from the crown or a leaf emerging through the sheath of a leaf from the first crop that remains attached to stubble. This usually occurs within 5 days after harvest, depending on first crop maturity at harvest.

Generally, the second crop begins to initiate when the first crop approaches harvest moisture (18 to 21 percent). It is not uncommon to see second crop growth initiated prior to harvest of the first crop.

Shoots develop in the second crop as they do in the first crop. New leaves emerge through sheaths of leaves on the first crop stubble; eventually, internode formation occurs, followed by panicle initiation (PI) and panicle differentiation (PD), booting, heading, grain filling and maturity. Development of buds on the crown is essentially the same process of tillering without the presence of a distinct primary shoot.

Second crop growth is small and much more variable in all aspects compared with the first crop. There are fewer leaves and internodes per stem, a shorter maturation period (time from bud initiation to heading) and shorter mature plant height. There are fewer panicles per acre and per plant and fewer grains per panicle. Second crop yields are generally less than 40 percent of first crop yields. Second crop growth and development are limited by declining day length and falling temperatures at the end of summer and during the fall, which is opposite from the first crop that experiences mostly increasing day length and temperatures from planting to heading during the spring and early summer. The reduction in total sunlight translates to lower photosynthesis, which accounts in part for the lower yields. Reduced input costs often make ratoon cropping profitable despite lower yields.

Chapter 5

Weed Management

Eric Webster

Weeds are some of the most troublesome pests in rice production in the United States and throughout the world. Weeds compete with rice for water, nutrients, space and light. Direct losses from weed competition are measurable and can be great. Indirect losses such as increased costs of harvesting and drying, reduced quality and dockage at the mill and reduced harvest efficiency are not readily measured but can reduce profits. Therefore, weed control measures should encompass broad spectrum activity under different production practices and systems.

Numerous grasses, broadleaf weeds and sedges can be economically damaging in rice. It is estimated that more than 80 species belonging to more than 40 genera can be problem weeds in the U. S. rice production. Rice weeds can grow and thrive in aquatic, semi-aquatic and terrestrial environments. Some of the major weed problems, such as barnyardgrass, broadleaf signalgrass, red rice, hemp sesbania, alligatorweed, dayflower, jointvetch species and annual and perennial sedges can thrive in both aquatic and dryland situations. Nealy sprangletop and rice cutgrass are grass weeds that have become more widespread over the past few years. These weeds tend to be more common in reduced tillage areas or growing along levees.

In south Louisiana, a rice-crawfish rotation is a common practice, causing several weeds to become major problems as a result of the year-round aquatic environment associated with this production system. Ducksalad, grassy arrowhead, common arrowhead, creeping burhead, pickerelweed and roundleaf mud-plantain require high moisture to germinate and are much more aggressive in aquatic situations. Perennial grasses such as creeping rivergrass, knotgrass, brook paspalum and water paspalum are becoming more of a problem in Louisiana rice production due to a rice-crawfish rotation.

Although weeds vary in their ability to compete with rice, most fields contain a complex of weeds that will reduce yield and quality if an appropriate weed management strategy is not implemented. Rice weed control is best accomplished by using a combination of cultural, mechanical and chemical management practices. Relying on a single control practice seldom provides adequate weed management. A thorough knowledge of weeds present in each field is critical in developing appropriate management strategies.

Red Rice Management

The number 1 weed problem in Louisiana rice production is red rice. Red rice has been spread largely by planting commercial seed that is contaminated with red rice and movement of equipment from infested fields to clean fields. Red rice is similar to commercial rice and is considered by many to be in the same genus and species. Commercial rice and red rice can readily cross producing a wide phenotypic set of offspring. Besides reducing commercial rice yields, the red pericarp of this noxious plant can contaminate milled commercial rice. Additional milling can help remove the red discoloration, but often will lead to reduced head rice yields through breakage of kernels. Cooking attributes of rice can be altered if significant amounts of red rice are present in milled rice.

Presence of red rice dictates production systems and weed control options and decreases flexibility. Rotating rice with other crops can reduce future weed problems. Successful rotations with soybean, corn, sorghum or cotton have reduced levels of red rice. With the development of Clearfield rice, producers have an option to plant rice that is resistant to the imidazolinone family of herbicides. Imazethapyr (Newpath) was the first herbicide labeled for use in the Clearfield production system. This herbicide provides residual and postemergence activity on red rice and other grass and broadleaf weeds. Later the herbicide Beyond (imazamox) received a label for use as a late-season herbicide choice to control late emerging red rice and red rice plants that may have escaped an earlier Newpath application. This technology continues to be the best option for managing red rice in production rice. Producers are moving to a Clearfield production system to take advantage of the overall weed control program available with this system.

Herbicide Selection and Application

The most important factor in herbicide use is the selection of the proper herbicide. Producers should have a basic understanding and knowledge of the weeds present in production fields. Keeping visual and written records of each field from year to year is very important.

Six basic herbicide application timings should be considered when choosing a herbicide: (1) burndown prior to planting, (2) preplant incorporated, (3) preemergence prior to planting, (4) preemergence after planting, (5) delayed preemergence (drill-seeded only) and (6) postemergence.

When selecting a herbicide, it is very important to understand the basic activity of the herbicide. If a herbicide has contact activity, it must be applied to weeds that have emerged above the soil surface and, in most cases, above the flood level. Most herbicides that require foliage contact should have at least 75 percent of the plant above the water line. An herbicide with soil activity should be applied when the soil surface is exposed. Herbicides like pendimethalin provide little to no benefit if applied to a flooded field. Many herbicides labeled for use in rice have both residual and postemergence activity. It is very important to take advantage of the entire package the herbicide can deliver.

Burndown Herbicide Application

Based on Louisiana State University AgCenter recommendations, burndown herbicides should be applied no earlier than 6 to 8 weeks prior to planting and no later than 3 to 4 weeks prior to planting. If burndown herbicides are applied too early, weeds may be present at planting. Waiting too long before applying burndown herbicides may not allow enough time for herbicides to work properly prior to planting. This is a timing that is often missed in Louisiana because it is often made within one to two weeks prior to planting. Several herbicides are available for use as a burndown choice, and most options are applied based around glyphosate. Price is often factored in when selecting a burndown herbicide program, but in many cases, the cheapest option may not be the best for a given situation.

Preplant Incorporated Herbicide Application

The use of preplant incorporated (PPI) herbicides requires the application of a herbicide to the soil surface prior to planting followed by herbicide incorporation with a disk or a field cultivator. It is important for the field to be relatively free of vegetation and or large soil clods to allow for uniform herbicide application. Vegetation or soil clods can intercept the herbicide spray and prevent uniform application. It is important to apply the herbicide with adequate spray volume to insure a uniform application. When incorporating herbicides, the implement should be passed over the area twice, with the second pass running perpendicular or at an angle to the previous pass. When a highly water-soluble herbicide is used, incorporation can be achieved with water; however, incorporating with water can be inconsistent.

The number of acres receiving a PPI herbicide application in Louisiana has dropped drastically in recent years. This was an accepted practice for the management of red rice in south Louisiana. With the introduction of Clearfield rice, the use of PPI treatments has been reduced. The Clearfield rice system does have the option of a PPI application of imazethapyr (Newpath). When fuel costs are high and flushing is required to activate a PPI herbicide, the benefit of the PPI herbicide may be offset. In many cases, a PPI treatment provides better overall weed control, but with the additional costs, the added benefit is often unprofitable.

Preemergence Herbicide Application Prior to Planting

This practice is used on a regular basis throughout Louisiana, especially in water-seeded rice production in south Louisiana. The herbicide is applied prior to planting as a surface application frequently in conjunction with a burndown herbicide program. When applied in a burndown program, the preemergence herbicide works best if existing vegetation is small or the field area is sparsely vegetated.

In south Louisiana, producers often impregnate starter fertilizer with a herbicide with preemergence activity. The field is flooded for seeding; starter fertilizer is impregnated with the herbicide and then is applied to the flooded field. Herbicides with high water solubility wash off the fertilizer granule and make soil contact, thereby providing preemergence herbicidal activity.

Preemergence Herbicide Application Following Planting

This practice is used most often in drill-seeded rice. Immediately after rice is planted, a herbicide is applied to the soil surface. Within a 24- to 48-hour period after herbicide application, adequate rainfall (1 inch or more) must occur or the field must be flushed for herbicide activation. Many producers attempt to avoid flushing by waiting on rainfall to save money; however, to receive optimum benefit from the herbicide, it must be activated by moisture. Efficacy is reduced the longer a herbicide remains on the soil surface without activation. Poor weed control is a common side effect of waiting for rainfall because weeds continue to grow during the waiting period.

A preemergence application can allow a rice crop to emerge and gain a competitive advantage on many weeds present in a given field. Producers should consider using a preemergence application on a portion of the operation to allow postemergence applications over a longer period of time during the growing season. If the producer has a basic knowledge of the history of weed pressure in a rice field, the grower can select fields most likely to benefit from a preemergence program.

Delayed Preemergence Herbicide Application

This herbicide application timing is primarily, if not exclusively, used in a drill-seeded rice production system. The rice crop is planted, and 4 to 7 days after planting, the herbicide is applied. This delay after planting allows the rice seed to begin the germination process, allowing the young seedling to get an initial growth advantage prior to herbicide application. This application usually follows a surface irrigation or rainfall within the 4- to 7-day interval after planting.

Postemergence Herbicide Application

Postemergence herbicide applications are those made any time after crop emergence. These applications include timings from very early postemergence on one- to two-leaf rice to salvage treatments applied late in the season to aid in harvest efficiency.

Postemergence herbicide applications are the most common timings for weed management in rice. Some postemergence herbicides have only contact activity, while others have both preemergence and postemergence activity. It is very important to understand the activity of the herbicide when selecting a postemergence herbicide. Postemergence herbicides almost always are most effective when applied to small actively growing weeds. The larger a weed the more difficult it is to manage with herbicides. A one- to two-leaf Texasweed is easier to control than a Texasweed with five to six leaves. When applying herbicides postemergence, it is important to avoid applications to weeds under any form of stress, especially moisture stress. Weeds that are not under moisture stress and are actively growing are controlled more easily than stressed weeds. This can also be true when temperatures are low enough to reduce plant activity or high enough to cause heat stress.

Weed Management Through Cultural Practices

Producers have several options available for managing weeds with cultural practices. These practices include conventional or reduced tillage, fallow versus crop rotation, rice cultivar selection, purchasing weed-free seed, water management, water- or drill-seeded rice planting systems, proper herbicide selection, timing of herbicide applications, herbicide application carrier volume and aerial versus ground herbicide application. While the use of herbicides to control weeds is not normally considered a cultural practice, the interaction of cultural practices with herbicide use must be considered.

Tillage and Rotation

In Louisiana, a strict no-tillage production system is rare; however, producers throughout the state practice both conventional tillage and reduced tillage or stale seedbed systems on their farms. Often, a producer will use a combination of these practices. Good records can determine which tillage practice should be used to manage each weed situation. Red rice can be managed through the use of stale seedbed or reduced tillage systems. Following harvest of a rice crop infested with red rice, not tilling the field will allow some red rice seed to decompose while lying on the soil surface. It also exposes the seed to depredation by wildlife. If the field is tilled, red rice seed will be buried and become dormant. The following spring a burndown herbicide may be employed once red rice has emerged.

In south Louisiana, the rice crawfish rotation has caused changes in weed management strategies. Tillage is often used on a very limited basis in this type of rotation. In severe cases, this lack of tillage has caused the weed spectrum in these fields to shift from annual grasses and broadleaf weeds to perennial aquatic weeds. To manage some of these difficult-to-control aquatic weeds, the area must be tilled and be fallowed or rotated to another crop, such as soybean, to take advantage of conventional tillage and herbicide rotation.

Cultivar Selection, Planting Rates and Row Spacing

The most important aspect of cultivar selection from a weed management stand point is selection of weed-free seed. Cultivar selection can also impact competition between rice and weeds.

Research has indicated some rice cultivars are more competitive with weeds than others. This is especially true of the once popular taller cultivars. Semidwarf varieties are less competitive than conventional tall varieties. Cultivars that produce large numbers of tillers also tend to be more competitive.

All rice cultivars have an optimum seeding rate that varies, depending on growth characteristics. Research conducted in Louisiana indicates that cultivars planted at the optimum seeding rate tend to be more competitive with weeds than when planted at low seeding rates. High seeding rates can be competitive with weeds, but intra-specific competition occurs at excessive seeding rates and yields are reduced. Establishing a good stand of rice and providing an environment that promotes rapid growth help to minimize weed interference. Optimum plant populations and adequate fertility, insect, disease and water management contribute to the ability of rice plants to compete with weeds.

Water Management

Proper water management is a key component in controlling weeds. Several different water management schemes have evolved in Louisiana, and two major planting systems dictate the basic water-management strategies used by producers. Historically, a majority of Louisiana's rice is in Southwest Louisiana and most of this acreage was planted using a water-seeded system prior to the commercialization of Clearfield rice. The introduction of Clearfield herbicide resistant rice has caused a shift from water-seeded to dry-seeded rice in Southwest Louisiana. The remaining acreage grown in northeast Louisiana where dry seeding methods are more common.

Water-seeded Rice. In general, weed spectrum changes from a predominantly annual grass problem in drill-seeded rice to more aquatic weed problems in a water-seeded system. If a water-seeded system is used for several years, it may cause a shift in the weed spectrum from terrestrial to aquatic weeds. The predominant weeds found in this production system are ducksalad, grassy arrowhead, common arrowhead, creeping burhead, pickerelweed and roundleaf mudplantain.

Three types of water management systems are used by producers: (1) continuous flood, (2) pinpoint flood and (3) delayed flood. See General Agronomic Guidelines section for more information on water management systems.

Water seeding is strongly tied to weed management. Weed seeds have the same requirements for germination as rice – proper temperature, water and oxygen. By flooding a rice field before temperatures have risen to levels sufficient for germination, two of the requirements are at least minimized because over time the flooded soil will become saturated. Saturated soils have little dissolved oxygen in them; thereby reducing weed seed germination and emergence.

In a continuous flood system, aquatic weeds become a problem earlier in the season. For example, it is not unusual for ducksalad to emerge along with planted rice in a continuous flood system. When a pinpoint flood system is employed, the area is drained for a short period of time after planting, and aquatic weeds can be a problem. Red rice and annual grasses can begin to emerge if the drain period is long enough to allow oxygen to reach weed seeds. The object of a pinpoint flood is to allow for rice seedling establishment before the soil dries. If soil is allowed to dry, annual grasses and other terrestrial weeds can and will emerge. Annual grass weeds are less of a problem in continuous and pinpoint flood systems, but producers must manage a pinpoint system closely to prevent soils from drying.

The third water management system is a delayed flood in a water-seeded system. From a weed control standpoint, this is not as practical if producers intend to manage weeds by flooding. In most instances, aquatic weeds create fewer problems in this type of flood management. With the development of Clearfield rice, this flooding practice has become more common because producers now have the ability to use herbicides to control red rice and other annual grasses.

When a water-seeded system is used, herbicide applications are generally applied postemergence. Prior to the development of Clearfield rice, the herbicides thiobencarb and molinate were the only available herbicides that could be incorporated prior to planting. The development of herbicide-resistant rice, introduction of new herbicides and the loss of molinate have nearly eliminated the preplant incorporated applications. It is very important to apply postemergence applications in a timely manner, choose the correct herbicide and apply it at proper rates.

Dry-seeded Rice. In this system, 4 to 6 weeks may elapse between planting and permanent flood establishment. Controlling weeds during this period is critical for maximizing yields. Annual grasses, such as barnyardgrass, broadleaf signalgrass and sprangletop species, and broadleaf weeds, such as Texasweed, eclipta, Indian jointvetch and hemp sesbania, can become established. Timely herbicide applications made to small weeds, surface irrigations, often referred to as flushes, to activate herbicides, and establishment and maintenance of a permanent flood as soon as possible will improve weed control. In south Louisiana, permanent floods are generally established on two- to three-leaf rice; in northeast Louisiana, the permanent flood may not be established until rice is in the five-leaf to one-tiller stage.

In dry-seeded systems, constructing levees as soon as possible after planting can improve weed control by allowing fields to be surface irrigated and flooded in a timely manner. Without levees, using water as a management tool is impossible. On coarse textured, silt loam soils, establishing levees is much easier than on finer-textured, clay soils. Although rainfall shortly after planting is beneficial for establishing a stand of rice and reducing the need for surface irrigation, excessive rainfall can prevent levee construction on clay soils. Establishing levees as soon as the rice is planted, when the soil is still relatively dry, can prevent or reduce problems encountered in preparing levees on wet soils.

Management of weeds is critical for optimum rice production in both water- and dry-seeded systems. Although herbicide options and management strategies differ under these systems, managing herbicides and water in a timely manner is critical.

Adjuvants and Spray Additives

Technology advances have brought about many changes in adjuvants. The standard adjuvants like nonionic surfactants (NIS) and crop oil concentrates (COC) have been around for years with little change in formulations. New surfactants, such as organosilicone and methylated seed oils and the addition of fertilizers, like urea, to NIS to improve herbicide uptake have made a major impact on herbicide application. Many herbicides depend on certain adjuvants to maximize activity, and producers and applicators should be familiar with the importance of proper adjuvant selection.

Postemergence herbicide performance can be greatly influenced by adjuvants. Adjuvant cost is much lower than the cost of a herbicide application, especially when several herbicides are applied as a mixture. Not using an adjuvant or selecting a poor quality adjuvant can reduce weed control. Consult the herbicide label for recommendations of the proper type and rate of the adjuvant to use.

Weed Resistance to Herbicides

Some weeds have developed resistance to herbicides in Louisiana. In situations where weeds are not controlled with labeled rates of herbicides applied under environmental conditions that are favorable for herbicide activity, these weeds may be resistant. Repeated use of propanil has resulted in the development of biotypes throughout the mid-South that are resistant to the herbicide. Aquatic weeds, such as ducksalad, have developed resistance to herbicides in all rice-growing states.

Changing herbicides and crops and applying herbicide mixtures with different modes of action may prevent or delay development of resistance in Louisiana. Rice producers in Louisiana have been fairly successful at keeping resistance problems to a minimum because of the lack of a standard program across the state. Production systems vary widely in Louisiana compared with other states, and this helps keep herbicide resistance manageable in Louisiana rice.

Rotating rice with soybean or other crops will allow use of soil-applied herbicides or postemergence grass herbicides that can control troublesome weeds. These herbicides have mechanisms of action that often differ from most rice herbicides. If weed resistance is suspected, contact your LSU AgCenter extension agent so an alternative herbicide program can be developed and resistance can be monitored. In addition to developing potential weed resistance, repeated use of a single herbicide will exploit the weakness of the herbicide and may shift the weed spectrum to weeds that may be more difficult to control. An example of this is the continued use of Facet (quinclorac)-only weed management program, resulting in a shift from barnyardgrass to sprangletop species as the primary annual grass weed.

Weed species found in Louisiana Rice

Grasses

Annual

- Amazon sprangletop *Leptochloa panicoides*
- Barnyardgrass *Echinochloa crus-galli*
- Broadleaf signalgrass *Urochloa platyphlla*
- Fall panicum *Panicum dichotomiflorum*
- Large crabgrass *Digitaria sanguinalis*
- Junglerice *Echinochloa colona*
- Nealley's sprangletop *Leptochloa nealleyi*
- Red rice *Oryza sativa*

Perennials

- Brook crowngrass/Brook paspalum *Paspalum acuminatum*
- Creeping rivergrass *Echinochloa polystachya*
- Knotgrass *Paspalum distichum*
- Rice cutgrass *Leersia oryzoides*
- Southern watergrass *Luziola fluitans*
- Water paspalum *Paspalum hydrophilum*
- Waxy mannagrass *Glyceria declinata*

Broadleaf

Annual

- Cutleaf groundcherry *Physalis angulata*
- Eclipta *Eclipa prostrata*
- False pimpernel *Lindernia* spp.
- Gooseweed *Sphenolcea zeylanica*
- Hedge hyssop *Gratiola* spp.
- Hemp sesbania *Sesbania herbacea*
- Indian/rough jointvetch *Aeschynomene indica*
- Indian toothcup *Rotala indica*
- Ladysthumb *Polygonum persicaria*
- Pennsylvania smartweed *Polygonum pensylvanicum*
- Purple ammannia *Ammannia coccinea*
- Redweed *Melochia corchorifloia*
- Spreading dayflower *Commelina diffusa*
- Texasweed *Caperonia palustris*

Aquatics

- Alligatorweed *Alternathera philoxeroides*
- Common arrowhead *Sagittaria latifolia*
- Creeping burhead *Echinodrous cordifolius*
- Ducksalad *Heteranthera limosa*
- Grassy arrowhead *Sagittaria lancifolia*
- Pickerelweed *Pontederia cordata*
- Red ludwigia/March seedbox *Ludwigia palustris*
- Roundleaf mudplantain *Heteranthera reniformis*

Sedges and Rushes

- Rice flatsedge *Cyperus iria*
- Yellow nutsedge *Cyperus esculentus*
- Bog bulrush *Schoenoplectus mucronatus*
- Spikerush *Eleocharis* spp.

Grasses

Amazon Sprangletop

Leptochloa panicoides

Keys to Identification: Tufted summer annual; no hairs on leaf blade, keeled leaf sheath, long membranous ligule; seedhead is a long, narrow panicle

Distribution: All Louisiana parishes. Native of Brazil

Barnyardgrass

Echinochloa crus-galli

Keys to Identification: Smooth leaf and leaf sheath with no ligule; tuffed erect summer annual grass with fibrous root; seed often awned.

Distribution: All Louisiana parishes. Introduced from the Old World.

Grasses

Broadleaf Signalgrass

Urochloa platyphylla

Summer annual

Keys to Identification: Spreading growth habit; stem bent at nodes; hairy leaf blades on lower leaves; leaf sheath hairy along margin; membranous ligule fringed with hairs; seed-head 2-6 long racemes, distinctive

Distribution: All Louisiana parishes. Native to Southeast U.S.




Fall Panicum

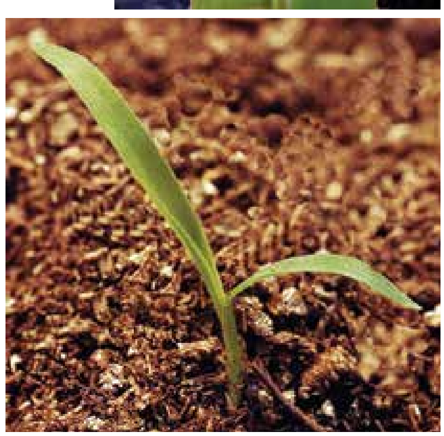
Panicum dichotomiflorum

Erect summer annual

Keys to Identification: Bent and branched nodes; leaf blade may be hairy on upper surface; membranous ligule; large panicle seedlhead.

Distribution: All Louisiana parishes.



Grasses

Large Crabgrass

Digitaria sanguinalis

Tufted summer annual

Keys to Identification: Dense hairs on leaf blades and sheaths; membranous ligule; prostrate stems with spreading habit and rooting at nodes.

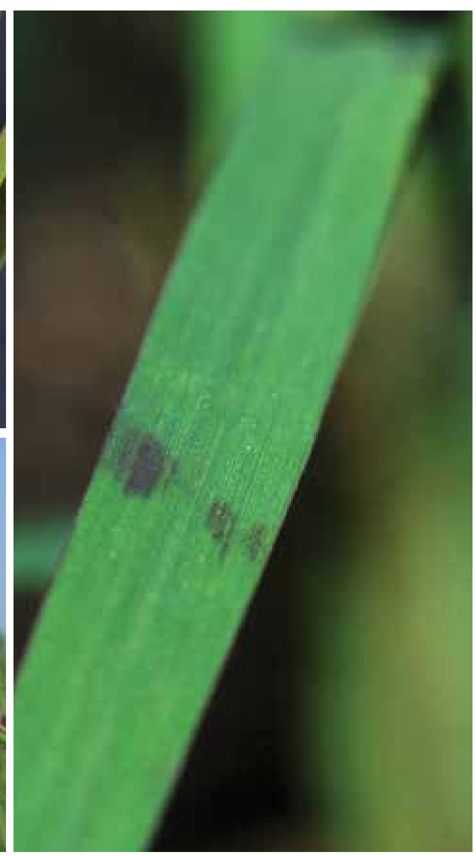
Distribution: All Louisiana parishes.

Junglerice

Echinochloa colona

Keys to Identification: Smooth leaf and leaf sheath with no ligule; purple bands on leaf tufted erect summer annual grass with fibrous root; seed awnless.

Distribution: All Louisiana parishes.



Grasses

Nealley's Sprangletop

Leptochloa nealleyi

Keys to Identification: Erect annual 3-5 ft tall; small hairs on leaf sheath up to 4 leaf stage, older plants smooth to slightly hairy on leaf sheath, keeled leaf sheath, short membranous ligule; tall and narrow seedhead, 10-20 inches long 1-1.5 inches wide.

Distribution: Southwest and Southeast Louisiana parishes.

Red Rice

Oryza sativa

Keys to Identification: Tufted summer annual; leaves long and rough; large triangular ligule; seedhead a loose erect paricle.

Distribution: All Louisiana parishes.

Grasses

Brook crowngrass, Brook paspalum

Paspalum acuminatum

Perennial grass

Keys to Identification: Solid stem; lacks hair, leaf blades wide in proportion to stem; membranous ligule; seedhead winged rachis.

Distribution: South Louisiana parishes.

Creeping rivergrass

Echinochloa polystachya

Aquatic perennial grass

Keys to Identification: Solid stem; leaf blades narrow in proportion to stem; ligule fringe of hairs; hairy nodes; seedhead loose panicle.

Distribution: Southern Louisiana parishes.

Grasses

Knotgrass

Paspalum distichum

Perennial grass

Keys to Identification: Solid stem; leaf midvein not prominent; hairy nodes; leaf blade narrow in proportion to stem; membranous ligule with hair at collar region.

Distribution: All Louisiana parishes.

Rice cutgrass

Leersia oryzoides

Perennial

Keys to Identification: Long membranus ligule; upright growth pattern; pubescent (hairy) nodes; long course leaves; short stiff hairs growing downward on stem.

Distribution: All Louisiana parishes.

Grasses

Southern watergrass

Luziola fluitans

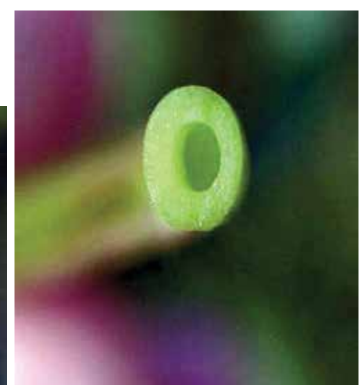
Aquatic perennial grass

Keys to Identification: Floating slender stems; roots at nodes; short light green leaves less than 3 inches; membranus ligule.

Distribution: All Louisiana parishes.

Water Paspalum

Paspalum hydrophilum



Perennial grass

Keys to Identification: Hollow stem; prominent white leaf midvein; lacks hair at nodes; leaf blade wide in proportion to stem; membranous ligule.

Distribution: Southern Louisiana parishes.

Grasses

Waxy mannagrass

Glyceria declinata

Perennial grass

Keys to Identification: Found in wet areas; tufted plant with upright growth; long membranus ligule.

Distribution: South Louisiana parishes.

Broadleaf Weeds

Cutleaf groundcherry

Physalis angulata

Annual

Keys to Identification: Leaves alternate, lanceolate to ovate, edges coarsely irregular; berry fruit enclosed in an enlarged rounded calyx.

Distribution: All Louisiana parishes.

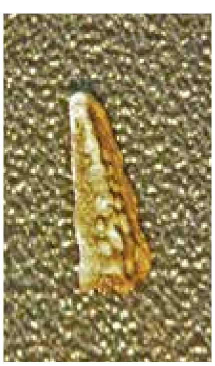
Eclipta

Eclipa prostrata

Annual

Keys to Identification: Erect to spreading; spatulate cotyledons; opposite, elliptic leaves, hairy on lower leaf surface, leaf margins slightly toothed; flowers are two solitary heads.

Distribution: All Louisiana parishes.



Broadleaf Weeds

False pimpernel

Lindernia spp.

Annual

Keys to Identification: Mat-forming; leaves opposite, elliptic to ovate, sometimes pubescent; stems creeping, sometimes rooting at nodes.

Distribution: All Louisiana parishes, wetlands and flooded rice fields.

Gooseweed

Sphenoclea zeylanica

Annual

Keys to Identification: Erect, branching annual; leaves elliptic with smooth margins and varying in size; stems often contain a milky, watery sap and terminate in a dense spike with many small white flowers.

Distribution: All Louisiana parishes.

Broadleaf Weeds

Hedge Hyssop

Gratiola spp.

Annual

Keys to Identification: Erect, branching, herbaceous; leaves elliptic to ovate, sometimes finely serrated; stems often rooting at nodes.

Usually occurring in spring in rice field left flooded during the winter.

Distribution: All Louisiana parishes.

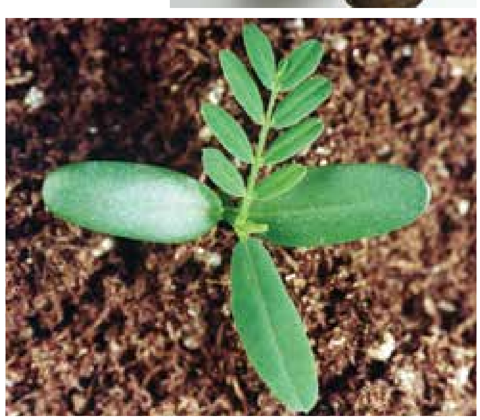
Hemp Sesbania

Sesbania herbacea

Annual

Keys to Identification: Lance shaped cotyledons; first true leaf is simple; alternate, pinnately compound leaves with stipules; yellow petals on flower; distinctive curved seedpod.

Distribution: All Louisiana parishes.



Broadleaf Weeds

Indian/Rough Jointvetch

Aeschynomene indica

Annual

Keys to Identification: Ovate cotyledons; first true leaf pinnately compund; alternate pinnately compound leaves with lance shaped stipules; yellowish to reddish-purple flower petals; seedpod compressed, oblong and breaks into segments easily.

Distribution: All Louisiana parishes.

Indian Toothcup

Rotala indica

Annual

Keys to Identification: Erect and branching; leaves opposite, lanceolate to spatulate; stems round to square.

Distribution: All Louisiana parishes in wetlands, ditches and flooded rice fields.

Broadleaf Weeds

Ladysthumb

Polygonum persicaria

Annual

Keys to Identification: Erect or prostrate; lance-shaped cotyledons; leaves are lance shaped with pointed tips; stems are round and smooth with swollen nodes, ocrea surrounding nodes is fringed with hair-like bristles.

Distribution: All Louisiana parishes.

Pennsylvania Smartweed

Polygonum pensylvanicum

Annual

Keys to Identification: Erect or prostrate; lance-shaped cotyledons; leaves are lance-shaped with pointed tips, usually with a purple watermark in the center of the leaf; stems are round and smooth with swollen nodes; ocrea lacks hair-like bristles.

Distribution: All Louisiana parishes.

Broadleaf Weeds

Purple Ammannia

Ammannia coccinea

Annual

Keys to Identification: Erect, herbaceous annual; reddish glabrous linear to linear-lanceolate cotyledons; leaves opposte, similar shaped, sometimes clasping; stems are square, slightly winged.

Distribution: All Louisiana parishes.

Redweed

Melochia corchorifolia

Annual

Keys to Identification: Herbaceous; round cotyledons; ovate to lanceolate leaves with serrated margins; hairy stem; flower in compact head-like cymes.

Distribution: All Louisiana parishes.

Broadleaf Weeds

Spreading dayflower

Commelina diffusa

Annual

Keys to Identification: Diffusely branching herbaecous annual; seedling unbranched, glabrous, grass-like; leaves glabrous, lanceolate, acuminate or acute; stems glabrous.

Distribution: All Louisiana parishes.

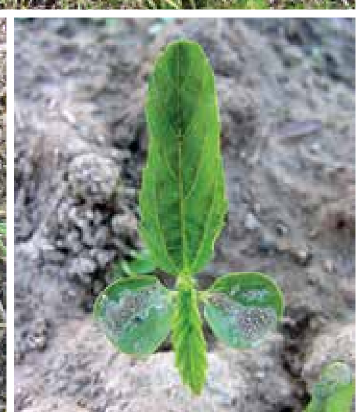
Texasweed

Caperonia palustris

Annual

Keys to Identification: Herbaceous annual, with smooth cotyledons and coarse hairy stems and petioles; alternate lanceolate leaves with serrated margins; monoecious plants (separate male and female flowers).

Distribution: All Louisiana parishes.



Broadleaf Weeds

Alligatorweed

Alternanthera philoxeroides

Aquatic Annual

Keys to Identification: Erect or prostrate; lance-shaped cotyledons; leaves are lance-shaped with pointed tips, usually with a purple watermark in the center of the leaf; stems are round and smooth with swollen nodes.

Distribution: All Louisiana parishes.

Bulltongue Arrowhead

Sagittaria lancifolia

Aquatic Annual

Keys to Identification: Erect aquatic perennial; leaves on long, spongy petioles, broadly elliptic to oblong-elliptic; flowers unisexual, with three white petals

Distribution: All Louisiana parishes in wetlands, ditches, flooded rice fields and pond edges.

Broadleaf Weeds

Common Arrowhead

Sagittaria latifolia

Aquatic Perennial

Keys to Identification: Erect aquatic perennial; leaves variable on long, spongy petioles sagittate, 3-lobed with basal lobes apicies varying from broadly obtuse to narrowly acute; flowers unisexual, with three white petals.

Distribution: All Louisiana parishes in wetland, ditches, flooded rice fields and pond edges.

Creeping Burhead

Echinodorus cordifolius

Aquatic Annual/perennial

Keys to Identification: Leaf blades broadly ovate; petioles submerged with spongy cells at base; white flowers on arching scape.

Distribution: All Louisiana parishes.

Broadleaf Weeds

Ducksalad

Heteranthera limosa

Aquatic Annual/Perennial

Keys to Identification: Tufted but spreading from rhizomes; leaves linear to oblanceolate; stems fleshy, rooting at the nodes; plants having a white or blue solitary flower.

Distribution: All Louisiana parishes.

Pickerelweed

Pontederia cordata

Aquatic perennial

Keys to Identification: Erect; leaves ovate to elliptical early, becoming cordate-sagitate; stems short, stout, somewhat succulent; flowers blue or lavender on a spike.

Distribution: All Louisiana parishes - wetlands, ditches, flooded rice fields and pond edges.

Broadleaf Weeds

Red Ludwigia/Marsh Seedbox

Ludwigia palustris

Perennial

Keys to Identification: Mat-forming, prostrate and creeping; leaves opposite, elliptic to ovate.

Distribution: All Louisiana parishes.

Roundleaf Mudplantain

Heteranthera reniformis

Aquatic Annual/Perennial

Keys to Identification: Tufted but spreading from rhizomes; leaves linear early, becoming cordate or reniform; stems fleshy, rooting at the nodes; flowers multiple white or pale blue on a raceme.

Distribution: All Louisiana parishes.

Sedges and Rushes

Rice Flatsedge

Cyperus iria

Annual

Keys to Identification: Erect tufted annual; leaves three-ranked, linear-lanceolate; stems triangular, glabrous, mutiple fruiting stems from plant base.

Distribution: All Louisiana parishes.

Yellow Nutsedge

Cyperus esculentus

Perennial

Keys to Identification: Erect, colonial, perennial; leaves three-ranked, prominent midvein, radually tapering to a sharp point; stems triangular, rarely branching, borne from a tuber or basal bulb.

Distribution: All Louisiana parishes.

Sedges and Rushes

Bog Bulrush

Schoenoplectus mucronatus

Perennial

Keys to Identification: Herbaceous plant; erect, rhizomatous.

Distribution: All Louisiana parishes - wetlands, ditches and flooded rice fields.

Spikerush

Eleocharis spp.

Annual/Perennial

Keys to Identification: Rhizomatous, sometimes mat-forming plant; stems often round, sometimes square and smooth terminating in a single erect spike.

Distribution: All Louisiana parishes - wetlands, ditches and flooded rice fields.

Chapter 6

Disease Management

Don Groth, Clayton Hollier and Chuck Rush

Disease damage to rice can greatly impair productivity and sometimes destroy a crop. The United States does not have any of the destructive viral diseases present in other rice-growing areas of the world, but fungal diseases are prevalent and very damaging to Louisiana rice. Several bacterial diseases have been found, but significant yield losses have only been associated with bacterial panicle blight.

Direct losses to disease include reduction in plant stands, lodging, spotted kernels, fewer and smaller grains per plant and a general reduction in plant efficiency. Indirect losses include the cost of fungicides used to manage disease, application costs and reduced yields associated with special cultural practices that reduce disease but may not be conducive to producing maximum yields.

The major diseases of rice in the United States are bacterial panicle blight (Figs. 6-2 and 6-3) caused by B*urkholderia glumae* and *Burkholderia gladioli*; fungal diseases including blast, caused by *Pyricularia grisea* (Figs. 6-5 to 6-8); stem rot, caused by *Magnaporthe salvinii (Sclerotium oryzae)* (Figs. 6-33 and 6-34); sheath blight, caused by *Thanatephorus cucumeris* (*Rhizoctonia solani*) (Figs. 6-25 to 6-28); brown spot, caused by *Cochiobolus miyabeanus* (Figs. 6-9 and 6-10); narrow brown spot, caused by *Sphaerulina oryzina* (*Cercospora janseana*) (Figs. 6-20 and 6-21); and kernel smut, caused by *Neovossia horrida* (Fig. 6-16). Seedling diseases caused by species of *Achlya* and *Pythium* (Figs. 6-35, 6-36 and 6-37) also are important in water-seeded rice.

Minor diseases include crown rot (Fig. 6-11), causal agent believed to be an *Erwinia* sp.; leaf scald, caused by *Gerlachia oryzae* (Figs. 6-17 and 6-18); leaf smut, caused by *Entyloma oryzae* (Fig. 6-19); sheath rot, caused by *Sarocladium oryzae* (Fig. 6-30); stackburn disease, caused by *Alternaria padwickii* (Fig. 32); white leaf streak, caused by *Mycovellosiella oryzae* (*Ramularia oryzae*) (Fig. 6-38); sheath blotch, caused by *Pyrenochaeta oryzae* (Fig. 6-29); sheath spot, caused by *Rhizoctonia oryzae* (Fig. 6-31); crown sheath rot, caused by *Gaeumannomyces graminis* var. *graminis* (Fig.s 6-12 and 6-13); black kernel, caused by *Curvularia lunata* (Fig. 6-4); seedling blights, caused by various fungi (Fig. 6-24); bacterial leaf blight (Fig. 6-1); false smut, caused by *Ustilaginoidea virens* (Fig. 6-14); root rots, caused by several fungi (Fig. 6-23); and several miscellaneous leaf, stem and glume spotting diseases. Several diseases caused by other sclerotial fungi are also found in Louisiana but are not significant. An undefined pathogen complex acting alone or with insect damage (feeding) also causes the grain and kernel discoloration called "pecky" rice (Fig. 6-15).

The physiological disorders straighthead (Fig. 3-2) and bronzing or zinc (Zn) deficiency (Fig. 3-6) occur throughout the southern rice area and are locally severe. Cold injury, salt damage and nutrient deficiencies can be confused with disease symptoms. Two minor diseases of rice in Louisiana are caused by small parasitic round worms called nematodes. These are white tip, caused by *Aphelenchoides besseyi* (Fig. 6-39), and root knot, caused by *Meloidogyne* species (Fig. 6-22).

The first step toward disease management is identification followed by careful field scouting to determine the extent of disease. Diseases known to occur in Louisiana and their causal agents are listed in Table 6-1. A guide for rapid identification of the major diseases is given in the following section (Table 6-2). Knowing the level of resistance of the variety to major diseases can be useful in determining the probability of having problems warranting preventive management measures. The list of available variety resistance can change over time, so consult LSU AgCenter publication 2270, "Rice Varieties and Management Tips." Scouting information or disease thresholds and management information are summarized for the major diseases in the last section of this chapter.

Use of foliar fungicides to manage rice diseases is often justified under conditions where environmental factors favor development of severe disease. Some factors that affect the probability of fungicide use being warranted include disease history in the field, the resistance of the variety, the yield potential, intended use (seed or grain), date of planting and ratoon crop potential. Always follow label directions. As the list of labeled fungicides may change, contact your LSU AgCenter extension agent for current information on fungicides available for rice disease management. A rice disease content oriented webpage www.lsuagcenter.com/en/crops_livestock/rice/diseases has been setup to provide up to date rice disease control information and additional resources not available in this publication.

Rice Disease Identification

Each year, the Louisiana rice crop is affected by many diseases. Severity of symptoms often varies because of varietal resistance, environmental conditions and plant growth stage. Also, not all symptoms typical of a disease occur on a single plant. It is important to look at several plants, from several areas of the field, to establish an accurate diagnosis. In the text, all symptoms known to occur are described but not all will be expressed. Use the guide for identification of rice diseases present in Louisiana to decide which diseases are present. The diseases are divided into sections based on what plant part is affected. Several diseases, however, may affect more than one part of a rice plant. When a disease is identified, information is provided in the text for managing the disease.

Table 6-1. Rice diseases and disorders in Louisiana.

Common Name	Pathogen Name or Cause
Bacterial diseases	
Bacterial blight like disease	*Xanthomonas oryzae* pv. *oryzae* (Ishiyama) Swings et al. = X. *campestris* pv. *oryzae* (Ishiyama) Dye
Bacterial panicle blight	*Burkholderia glumae* and *Burkholderia gladioli (Severin) Yabuchi, et al.*)
Crown rot	*Erwinia chrysanthemi* Burkholder et al.
Pecky rice (kernel spotting)	Damage by bacteria (see also under fungal and miscellaneous diseases)
Fungal diseases	
Black kernel	*Curvularia lunata* (Wakk.) Boedijn (teleomorph: *Cochiobolus lunatus* R.R. Nelson & Haasis)
Blast (leaf, rotten neck)	*Pyricularia grisea* Sacc.=P. *oryzae* Cavara (teleomorph: neck, nodal and collar) *Magnaporthe grisea* (Hebert) Barr)
Brown spot	*Cochliobolus miyabeanus* (Ito & Kuribayashi) Drechs. ex Dastur (anamorph: *Bipolaris oryzae* (Breda de Haan) Shoemaker)
Crown sheath rot	*Gaeumannomyces graminis* (Sacc.) Arx & D. Olivier
Downy mildew	*Sclerophthora macrospora* (Sacc.) *Thirumalachar* et al.
False smut	*Ustilaginoidea virens* (Cooke) Takah.
Kernel smut	*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc. = Neovossia horrida (Takah.) Padwick & A. Khan
Leaf smut	*Entyloma oryzae* Syd. & P. Syd.

Common Name	Pathogen Name or Cause
Fungal diseases continued	
Leaf scald	*Microdochium oryzae* (Hashioka & Yokogi) Samuels & I.C. Hallett = Rhynchosporium oryzae Hashioka & Yokogi
Narrow brown leaf spot	*Cercospora janseana* (Racib.) O. Const = *C. oryzae* Miyake (teleomorph: *Sphaerulina oryzina* K. Hara)
Pecky rice (kernel spotting)	Damage by many fungi including *Cochliobolus miyabeanus* (Ito & Kuribayashi) Drechs. ex Dastur, *Curvularia* spp., *Fusarium* spp., *Microdochium oryzae* (Hashioka & Yokogi) Samuels & I.C. Halett, *Sarocladium oryzae* (Sawada) W. Gams & D. Hawksworth and other fungi
Root rots	*Fusarium* spp., *Pythium* spp., *P. dissotocum* Drechs., *P. spinosum* Sawada
Seedling blight	*Cochliobolus miyabeanus* (Ito & Kuribayashi) Drechs. ex Dastur, Curvularia spp., *Fusarium* spp., *Rhizoctonia solani* Kuhn, *Sclerotium rolfsii* Sacc. (teleomorph: *Athelia rolfsii* (Curzi) Tu & Kimbrough), and other pathogenic fungi.
Sheath blight	*Thanatephorus cucumeris* (A.B. Frank) Donk (anamorph: *Rhizoctonia solani* Kuhn)
Sheath blotch	*Pyrenochaeta oryzae* Shirai ex Miyake
Sheath rot	*Sarocladium oryzae* (Sawada) W. Gams & D. Hawksworth = *Acrocylindrium oryzae* Sawada
Sheath spot	*Rhizoctonia oryzae* Ryker & Gooch
Stackburn	*Alternaria padwickii* (Ganguly) M.B. Ellis leaf spot) (Alternaria leaf spot)
Stem rot	*Magnaporthe salvinii* (Cattaneo) R. Krause & Webster (synanamorphs: *Sclerotium oryzae* Cattaneo, *Nakataea sigmoidae* (Cavara) K. Hara)
Water-mold (seed-rot and seedling disease)	*Achlya conspicua* Coker, A. *klebsiana* Pieters, *Fusarium* spp., *Pythium* spp., *P. dissotocum* Drechs., *P. spinosum* Sawada
White leaf streak	*Mycovellosiella oryzae* (Deighton & Shaw) Deighton
Disorders	
Bronzing	Zinc deficiency
Cold injury	Low temperatures
Panicle blight	Several causes – Wind damage, insect feeding, undetermined physiological factors
Pecky rice (kernel spotting)	Feeding injury by rice stink bug
Straighthead	Arsenic induced, unknown physiological disorder
Nematodes	
Root-knot	*Meloidogyne* spp.
White tip	*Aphelenchoides besseyi* Christie

Table 6-2. A guide to the identification of rice diseases present in Louisiana.

For identification of the major diseases, determine the part of the plant affected by the disease then refer to that section of Table 6-2. A list of the causal agents of all rice diseases known to occur in Louisiana is in Table 6-1.

I. Planted Seeds and Seedlings

Water-seeded rice

Symptoms	Disease
Seeds rotted after draining water from field; copper or greenish-brown spots on soil surfaces around or above rotted seeds; coarse, bristly mycelium radiating from seed (*Achlya* spp.) (Fig. 6-36) or gelatinous matrix surrounding each affected seed (*Pythium* spp.) (Fig. 6-37).	**Water Mold**
Seedlings 1-4 inches tall dying in seedling flood or after flushing seeded field.	**Pythium Seedling Blight**
Drill-seeded or dry broadcast rice: seedlings 1-4 inches tall dying: Brown spot on coleoptile or growing point (Fig. 6-24), seedlings suddenly dying.	**Seedling Blight**
Seedlings dying or turning white in patches or in short strips of drill row; fluffy white mycelium and small, round sclerotia (tan) may be present on soil surface at the base of affected seedlings after flushing seeded field.	**Sclerotium Seedling Blight**
Seedlings at the three- to five-leaf stage dying, often in patches, may have linear reddish-brown lesion on sheath of small seedlings, older seedlings with purple-brown blotches made up of small spots aggregating, leaves yellow or bronze (Fig. 3-6), lower leaves floating on surface of flood water, seedlings dying in deeper water and disappearing below surface of water.	**Bronzing** See also Salinity and Cold Injury.

II. Roots and Crown (Root-Stem Interface)

Symptoms	Disease
Crown area decayed with soft rot, black or dark brown with streaks extending to the lower internodes of culms (Fig. 6-11), fetid odor of bacterial soft rot, tillers dying one at a time; roots dying and turning black, adventitious roots produced at node above crown area. A similar discoloration of the crown may be caused by applying hormonal herbicide such as 2,4-D too early.	**Crown Rot**
Roots turning black or brown, decayed, reduced root volume, roots dying (Fig. 6-23).	**Root Rot**
Roots with swollen areas, found only under dryland conditions (Fig. 6-22).	**Root Knot**

III. Leaf Blades

Symptoms	Disease
Lesions varying from small round, dark brown spots, to oval spots with narrow reddish-brown margin and gray or white center with dark circular line (Fig. 6-5). Spots elongated, diamond-shaped or linear with gray dead area in center surrounded by narrow reddish-brown margin.	**Leaf Blast**

Round to oval, dark brown lesions with yellow or gold halo (Fig. 6-10); as lesions enlarge, they remain round, with center area necrotic, gray and lesion margin reddish-brown to dark brown.	**Brown Spot**
Long, narrow brown or reddish-brown lesion (Fig. 6-20, 6-21); lesions 0.5 to 3 cm long, parallel with leaf veins and usually restricted to the area between veins; lesions may occur on leaf sheaths.	**Narrow Brown Leaf Spot**
Lesions similar to narrow brown leaf spot, but wider and white in the center (Fig. 6-38).	**White Leaf Streak**
Lesions begin at base of blade, spreading from leaf sheath or from infection point on leaf blade (Fig. 6-27). Lesions consist of alternating wide bands of cream-colored, greenish-gray or tan with narrow bands of reddish-brown or brown.	**Sheath Blight**
Lesions consist of wide bands of gray, dying tissue alternating with narrow reddish-orange bands (Fig. 6-17); band pattern in chevrons from leaf tip or edges of the leaf, sometimes lesions are gray blotches at leaf edge with reddish-brown margin, advancing edge of lesion usually has a yellow or gold area (Fig. 6-18) between reddish-brown margin and green, healthy tissues.	**Leaf Scald**
Small 1-2 mm, black linear lesions on leaf blade (Fig. 6-19), usually more lesions on tip half of the leaf blade, lesions may have dark gold or light brown halo, leaf tip dries as plants approach maturity, lesions on sheaths of upper leaves.	**Leaf Smut**
Round or oval white or pale tan spot with a narrow, red or reddish-brown margin (Fig. 6-32); often two adjacent spots coalesce to form an oval double spot; lesions are from 0.5 to 1 cm in diameter, spots with small black fruiting structures in the center.	**Stackburn**
Leaf tips turn white with a yellow area between the white tip and the healthy green area (Fig. 6-39); white areas sometimes occur on leaf edges; flag leaf blade twisted with poor emergence of the panicle; kernels aborted or poorly filled; grain distorted or discolored.	**White Tip**
Symptoms consist of elongated lesions near the leaf tip margin that start out water-soaked in appearance; lesions may reach several inches in length, turn white to yellow and then to gray (Fig. 6-1).	**Bacterial Leaf Blight like disease**

IV. Leaf Sheath and Stem

Water-soaked, gray-green lesions at water line (Fig. 6-28) during tillering or early jointing stages of growth, lesions becoming oval, white or straw-colored in center with reddish-brown edge (Fig. 6-26), lesions 1 to 2 cm wide and 3 to 4 cm long, lesions spreading up leaf sheaths and onto leaf blades, lesions discrete or forming a continuous band on sheath (Fig. 6-26) or leaf (Fig. 6-27) of alternating wide necrotic areas with narrow reddish-brown bands.	**Sheath Blight**

Black, angular lesions on leaf sheaths at water line on plants at tillering or early jointing stages of growth (Fig. 6-33); at later stages outer sheath drying, inner sheath discolored or with black angular lesion; culms discolored with dark brown or black streaks; raised areas of dark fungus mycelium on surface; gray mycelium inside of culm or at maturity culm collapsed with small, round black sclerotia in dead sheath tissues and inside of culm (Fig. 6-34). **Stem Rot**

Lesions on sheaths midplant, oval, pale green, turning cream or white in the center with a broad dark reddish-brown margin (Fig. 6-31). Lesions remain separate, not forming continuous bands on the sheath. **Sheath Spot**

Black to brown diffuse lesions on the sheath near the water line (Fig. 6-12). Perithecia necks protruding from upper surface and a thick fungal mat between leaf sheath and culm (Fig. 6-13). **Crown Sheath Rot**

Reddish- or purple-brown, netlike pattern on sheath below the collar of lower leaf blades (Fig.6-21), lesion oval, 1 to 2 cm wide and 3 to 5 cm long, leaf blades turning yellow and drying. (See Narrow Brown Leaf Spot) **Cercospora Net Spot**

General reddish-brown discoloration of flag leaf sheath or reddish-brown or yellow-tan spots with dark, irregular ring pattern inside of spots (Fig. 6-30); panicles emerging poorly; stem of panicle twisted; white "frosting" of conidia on inside of leaf sheath, florets of panicles on affected tillers discolored a uniform reddish-brown or dark brown. Grain does not fill or kernels are lightweight. **Sheath Rot**

Oblong zonate reddish lesions with black fruiting structures (pycnidia) in the center areas of the lesion (Fig. 6-29). **Sheath Blotch**

Narrow red-brown lesions on flag leaf sheath or penultimate leaf sheath after panicles emerge; lesions 0.5 to 1.5 mm wide and up to 1 to 3 cm long; lesions run parallel with veins in sheaths, affecting the tissues between veins (Fig. 6-21). **Narrow Brown Leaf Spot**

Collar of flag leaf discolored brown or chocolate brown; leaf blade detaches from sheath as lesion dies and dries (Fig. 6-7). **Blast on Flag Leaf Collar**

Culm nodes turn black or nodes become shriveled and gray as plants approach maturity (Fig. 6-6); nodes purple to blue-gray with conidia of the pathogen; culms and leaves straw-colored above affected node; culms lodge at affected nodes. **Node Blast**

V. Panicle, Florets and Grain

Panicle

The panicle may have one to all of the florets blighted with grains not filling or aborted. Florets are initially white or light gray on the basal third with a reddish-brown margin separating this area from the rest of the floret, which becomes straw colored (Fig. 6-3). The florets eventually become gray with growth of saprophytic fungi on the surface. Floret stems (panicle branches) stay green after the unaffected grain matures. **Bacterial Panicle Blight**

Node and surrounding area at base of panicle discolored brown or chocolate brown (Fig. 6-8); stem of panicle shrivels and may break; node purplish or blue-gray with conidia of the fungal pathogen; panicle white or gray; florets do not fill and turn gray; panicle branches and stems of florets with gray-brown lesions.	**Rotten Neck Blast**
Panicles upright, not falling over or slightly bent over because of sterility. Hulls distorted, parrot beak-shaped. Plants may not head at all (Fig. 3-1).	**Straighthead**
Internodal area above or below node at the base of the panicle turns light brown or tan-brown; affected area dies and shrivels; kernels in florets of lower portion of the panicle do not fill. (See Brown Spot and Narrow Brown Leaf Spot for more information.)	**Cercospora Neck Blight**
Single florets or several florets on a panicle branch turn light brown or straw-colored; floret stem with brown lesion; grain stops developing; florets turn gray.	**Panicle Blast**
Panicles twisted and deformed, unable to emerge from the leaf sheath and becoming twisted; the panicle is small, normally remaining green longer than usual; no seeds produced.	**Downy Mildew**
Panicles small, reduced number of spikelets and lemmas and paleas often absent on terminal portions of panicles.	**White Tip**

Florets and Grain

Single florets or several florets per panicle with brown, reddish-brown, purple or white surrounded by purple-brown spots (Fig. 6-15).	**Grain Spotting or Pecky Rice**
Maturing grain partially filled with or without grayish cast; powdery black mass on surface of the kernel and at seam between palea and lemma (Fig. 6-16) (rubs off easily onto fingers). (See Black Kernel)	**Kernel Smut**
Single florets or more commonly several florets in a panicle turn reddish-brown to dark brown (Fig. 6-30).	**Sheath Rot**
Single florets or several florets on a panicle straw colored, branches of panicle remain green (Fig. 6-3). The grain stops developing, and the florets turn gray.	**Bacterial Panicle Blight**
Maturing grain partially filled, shriveled, chalky, fuzzy black mass covering surface of the grain or at seam between palea and lemma (will not easily rub off on fingertips).	**Brown Spot**
Large orange fruiting structure on one or two grains in maturing panicle. When orange membrane ruptures, a mass of greenish-black spores is exposed (Fig. 6-14). Grain replaced by one or more sclerotia.	**False Smut**

Rice Disease in Louisiana

Bacterial Leaf Blight-Like

Bacterial leaf blight is caused by the bacterium *Xanthomonas campestris* pv. *oryzae*. It was first identified in the United States in Texas and Louisiana in 1987. Additional testing proved the bacterium was not the severe Asian strain. No major losses have been associated with this disease in the United States, but bacterial leaf blight in other parts of the world causes severe damage.

The blight bacterium overwinters in rice debris in the soil and on weed hosts. There is also a slight chance that seed may transmit the pathogen. The pathogen is spread by wind-blown rain, irrigation water, plant contact and probably on plant debris on machinery. High humidity and storms favor disease development. Watersoaked areas appear on the leaf margins near the tips, enlarge and turn white to yellow. As the lesions mature, they expand, turn white and then gray because of growth of saprophytic fungi (Fig. 6-1). The lesion may be several inches long. Contact your LSU AgCenter extension agent if you suspect this disease. Accurate identification is important since the symptoms can be confused with other diseases, especially leaf scald (Fig. 6-17), herbicide damage and other plant stress. Management practices include rotating to nongrass crops, tilling to destroy plant debris and avoiding contaminating the field through infected plant materials or irrigation water.

Fig. 6-1. Bacterial leaf blight.

Bacterial Panicle Blight

Rice produced in the southern United States has a long history of loss to panicle blighting of unknown etiology. Epidemics of panicle blight occurred during the 1995, 1998, 2000 and 2011 seasons, years of record-high night temperatures, with yield losses in some fields estimated to be as high as 40 percent. Earlier panicle blighting was attributed to abiotic factors, including high temperatures, waters stress or toxic chemicals near the root zone, but in 1996-97, the cause of panicle blighting in the southern United States was identified as the bacterial plant pathogen *Burkholderia glumae*. This bacterium was first described in 1967 in Japan as the cause of grain-rotting and seedling blighting. The disease was later reported from other Asian and Latin American countries. The symptoms of bacterial panicle blight include seedling blighting, sheath rot, and panicle blighting with significant yield losses. The pathogen forms a linear lesion on the flag-leaf sheath extending down from the leaf-blade collar. The lesion is distinct and has a reddish-brown border with the lesion center becoming necrotic and gray. The lesion may reach several inches in length. The panicle may have one to all of the florets blighted with grains not filling or aborted.

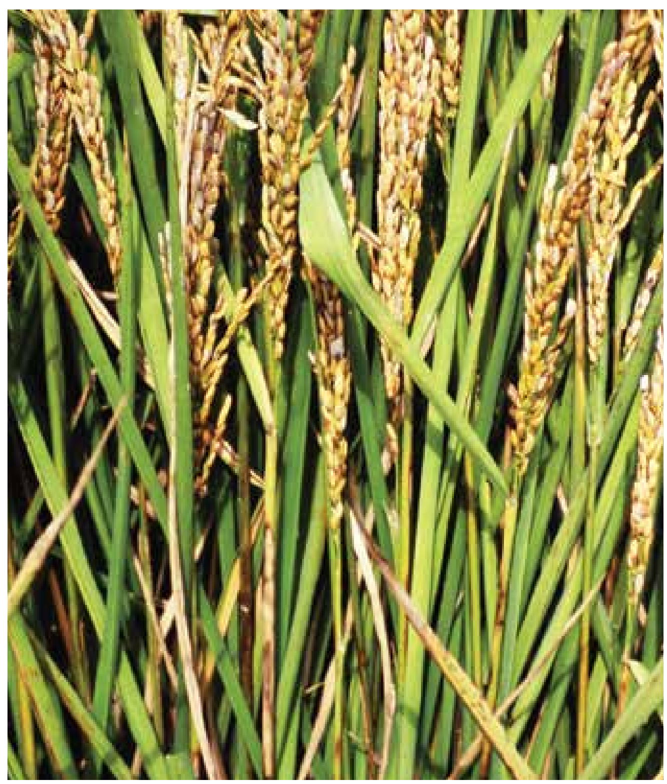


Fig. 6-2. Bacterial panicle blight.

Fig. 6-3. Bacterial panicle blight on kernels.

Affected panicles develop in circular patterns in the field (Fig. 6-2). Florets are initially white or light gray on the basal third with a reddish-brown margin separating this area from the rest of the floret, which becomes straw-colored (Fig. 6-3). The florets eventually become gray with growth of saprophytic fungi on the surface. Floret stems (panicle branches) stay green after the unaffected grain matures. *Burkholderia gladoli* was recently reported as associated with this disease on rice in Japan and the southern United States. This disease can cause severe disease under conditions of extended high temperatures, especially nighttime temperatures, and is ranked with sheath blight and rice blast for its potential to cause loss.

The term "panicle blight" has been used in the United States for more than 50 years, and bacterial panicle blight has been retained as the name of this disease. The bacterium is seed-borne, and rice crops planted with infected seeds can suffer severe losses. The pathogen has also been detected from the soil, but the importance to disease development is not known. Use of pathogen-free seeds is an important practice to reduce or manage the incidence of bacterial panicle blight. A method for testing rice seed-lots with PCR has been developed. No pesticides are currently recommended for control of this disease in the United States. Several varieties have partial resistance (LSU AgCenter publication 2270, "Rice Varieties and Management Tips").

Black Kernel

The fungus *Curvularia lunata* causes black kernel. The fungus causes severe grain discoloration (Fig. 6-4), and after milling, the kernels appear black. When infections are heavy, the fungus can cause seedling blights or weakened seedlings. This disease is rarely severe enough that management practices are recommended. Seed treatments to manage other diseases should reduce seedling damage. No other management measures are warranted.

Fig. 6-4. Black kernel.

Blast

Rice blast is caused by the fungus *Pyricularia grisea*. The disease is also called leaf blast, node blast, panicle blast, collar blast and rotten-neck blast, depending on the portion of the plant affected. Blast has been one of the most important diseases in Louisiana, causing severe yield losses to susceptible varieties under favorable environmental conditions.

Blast can be found on the rice plant from the seedling stage to maturity. The leaf blast phase occurs between the seedling and late tillering stages. Spots on leaves start as small white, gray or blue tinged spots that enlarge quickly under moist conditions to either oval or diamond-shaped spots or linear lesions with pointed ends with gray or white centers and narrow brown borders (Fig. 6-5). Leaves and whole plants are often killed under severe con-

Fig. 6-5. Leaf blast.

Fig. 6-6. Node blast.

ditions. Lesions on resistant plants are small brown specks that do not enlarge.

On stem nodes (Fig. 6-6), the host tissue turns black and becomes shriveled and gray as the plant approaches maturity. The infected area may turn dark purple to blue-gray because of the production of fungal spores. Culms and leaves become straw-colored above the infected node. Plants lodge or break off at the infected point, or they are connected only by a few vascular strands. Some varieties are infected where the flag leaf attaches to the sheath at the collar (Fig. 6-7). The lesion turns brown or chocolate-brown to gray, and the flag leaf becomes detached from the plant as the lesion area becomes dead and dry.

Rotten-neck symptoms appear at the base of the panicle starting at the node (Fig. 6-8). The tissue turns brown to chocolate brown and shrivels, causing the stem to snap and lodge. If the panicle does not fall off, it may turn white to gray or the florets that do not fill will turn gray. Panicle branches and stems of florets also have gray-brown lesions.

Fig. 6-7. Collar blast.

Fig. 6-8. Rotten neck blast.

Scouting a field for blast should begin early in the season during the vegetative phase and continue through the season to heading. Leaf blast will usually appear in the high areas of the field where the flood has been removed, lost or is shallow. Rice is most susceptible to leaf blast at the maximum tillering stage. Areas of heavy N fertilization and edges of the fields are also potential sites of infection. If leaf blast is in the field or has been reported in the same general area and if the variety is susceptible, fungicide applications are advisable to reduce rotten-neck blast.

The pathogen overwinters as mycelium and spores on infected straw and seed. Spores are produced from specialized mycelium called conidiophores and become wind-borne at night on dew or rain. The spores are carried by air currents and land on healthy rice plants. The spores germinate under high humidity and dew conditions and infect the plant. Generally, lesions will appear 4 to 7 days later, and additional spores are produced. Plants of all ages are susceptible. Medium-grain varieties are more susceptible to blast, especially during the leaf phase, than the long-grain varieties grown in Louisiana.

Environmental conditions that favor disease development are long dew periods, high relative humidity and warm days with cool nights. Agronomic practices that favor disease development include excessive N levels, late planting and dry soil (loss of flood). Several physiologic races of *P. grisea* exist, and disease development varies, depending on variety-race interactions.

The disease can be reduced by planting resistant varieties, maintaining a 4- to 6-inch flood, proper N fertilizer, avoiding late planting and by applying a fungicide at the rates and timings recommended by the Louisiana Cooperative Extension Service.

Brown Spot

Brown spot, caused by the fungus *Cochiobolus miyabeanus*, was one of the most prevalent rice diseases in Louisiana. It is also called Helminthosporium leaf spot. When *C. miyabeanus* attacks the plants at emergence, the resulting seedling blight causes sparse or inadequate stands and weakened plants. Leaf spots are present on young rice, but the disease is more prevalent as the plants approach maturity and the leaves begin to senesce.

Fig. 6-9. Brown spot, seedling.

Fig. 6-10. Brown spot.

Yield losses from leaf infection or leaf spots are probably not serious. When the fungus attacks the panicle, including the grain, economic losses occur. Heavy leaf spotting indicates an unfavorable growth factor, usually a soil problem.

The pathogen also attacks the coleoptiles, leaves, leaf sheath, branches of the panicle, glumes and grains. The fungus causes brown, circular to oval spots on the coleoptile leaves of the seedlings (Fig. 6-9). It may cause seedling blight.

Leaf spots are found throughout the season. On young leaves, the spots are smaller than those on older leaves. The spots may vary in size and shape from minute dark spots to large oval to circular spots (Fig. 6-10). The smaller spots are dark brown to reddish-brown. The larger spots have a dark brown margin and a light, reddish-brown or gray center with a gold halo. The spots on the leaf sheath and hulls are similar to those on the leaves.

The fungus attacks the glumes and causes a general black discoloration. It also attacks the immature florets, resulting in no grain development or kernels that are lightweight or chalky.

Brown spot is an indicator of unfavorable growing conditions, including insufficient N, inability of the plants to use N because of rice water weevil injury, root rot or other unfavorable soil conditions. As the plants approach maturity, brown spot becomes more prevalent and the spots are larger on senescing leaves.

Damage from brown spot can be reduced by maintaining good growing conditions for rice by proper fertilization, crop rotation, land leveling, proper soil preparation and water management. Seed-protectant fungicides reduce the severity of seedling blight caused by this seed-borne fungus. Some varieties are less susceptible than others.

Crown Rot

Crown rot is believed to be caused by a bacterial infection (possibly *Erwinia chrysanthemi*). This disease is rarely observed. Symptoms first appear during tillering. The crown area is decayed, with soft rotting, becoming black or dark brown with discolored streaks extending into the lower internodes of culms (Fig. 6-11). There is a fetid or putrid odor characteristic of bacterial soft rots, and tillers start dying one at a time. The roots also die and turn black. Adventitious roots are produced at the node above the crown area. A similar discoloration of the crown can be caused by misapplied herbicides. Control practices are not recommended.

Crown Sheath Rot

Crown sheath rot is caused by the fungus *Gaeumannomyces graminis* var. *graminis*. Other names

Fig. 6-11. Crown rot.

Fig. 6-12. Crown sheath rot.

Fig. 6-13. Crown sheath rot mycelium.

for this disease include brown sheath rot, Arkansas foot rot and black sheath rot. It has been considered a minor disease of rice, but reports from Texas suggest severe damage can occur. The pathogen kills lower leaves, thus reducing photosynthetic activity, causing incomplete grain filling, and plants can lodge.

Symptoms appear late in the season, usually after heading. Sheaths on the lower part of the rice plant are discolored brown to black (Fig. 6-12). Reddish-brown mycelial mats are found on the inside of infected sheaths (Fig. 6-13). Dark perithecia are produced within the outside surface of the sheath. Perithecia are embedded in the sheath tissues with beaks protruding through the epidermis. This disease can easily be confused with stem rot (Fig. 6-33).

The fungus survives as perithecia and mycelia in plant residues. Ascospores are wind-borne in moist conditions. The fungus has been reported to be seed-borne. Management practices have not been worked out for this disease.

Downy Mildew

Downy mildew is caused by the fungus *Sclerophthora macrospora*. In early growth stages, infected seedlings are dwarfed and twisted with chlorotic, yellow to whitish spots. Symptoms are more severe on the head. Because of failure to emerge, panicles are distorted, causing irregular, twisted and spiral heads that remain green longer than normal. This disease is extremely rare. No control measures are recommended.

Fig. 6-14. False smut.

False Smut

False smut, caused by the fungus *Ustilaginoidea virens*, is a minor disease in the United States and is sometimes epidemic in certain areas. The disease is characterized by large orange to brown-green fruiting structures on one or more grains of the mature panicle (Fig. 6-14). When the silver covering ruptures, a mass of greenish-black spores is exposed. The grain is replaced by one or more sclerotia. Most varieties appear to have a high level of resistance, and disease control measures generally are not required. Fungicides used to manage other diseases may be active against this disease.

Grain Spotting and Pecky Rice

Many fungi infect developing grain and cause spots and discoloration on the hulls or kernels. Damage by the rice stink bug, *Oebalus pugnax* F., also causes discoloration of the kernel. Kernels discolored by fungal infections or insect damage are commonly called

Fig. 6-15. Peck rice.

pecky rice (Fig. 6-15). This complex disorder involves many fungi, the white-tip nematode and insect damage. High winds at the early heading stage may cause similar symptoms. Proper insect control and disease management will reduce this problem.

Kernel Smut

This fungal disease is caused by *Neovossia barclayana*. Symptoms are observed at or shortly before maturity. A black mass of smut spores replaces all or part of the endosperm of the grain. The disease is easily observed in the morning when dew is absorbed by the smut spores. The spore mass expands and pushes out of the hull, where it is visible as a black mass (Fig. 6-16). When this spore mass dries, it is powdery and comes off easily on fingers. Rain washes the black spores over adjacent parts of the panicle. Affected grains are a lighter, slightly grayish color compared with normal grain.

Fig. 6-16. Kernel smut.

Usually, only a few florets may be affected in a panicle, but fields have been observed in Louisiana with 20 to 40 percent of the florets affected on 10 percent or more of the panicles in a field. Smutted grains produce kernels with black streaks or dark areas. Milled rice has a dull or grayish appearance when smutted grains are present in the sample. Because fewer kernels break when parboiled rice is milled, kernel smut can be a severe problem in processed rice. Growers are docked in price for grain with a high incidence of smut.

This disease is usually minor in Louisiana, but it can become epidemic in local areas. Some varieties are more susceptible and should be avoided where smut is a problem. Spores of the fungus are carried on affected seeds and overwinter in the soil of affected fields. The pathogen attacks immature, developing grain and is more severe when rains are frequent during flowering. Fungicide applications at booting can be affective for controlling this disease. Please contact your local LSU AgCenter extension agent for fungicide recommendations.

Leaf Scald

Fig. 6-17. Leaf scald.

This disease, caused by *Gerlachia oryzae*, is present in the southern rice area of the United States and in Louisiana annually. It affects leaves, panicles and seedlings. The pathogen is seed-borne and survives between crops on infected seeds. The disease usually occurs on maturing leaves. Lesions start on leaf tips or from the edges of leaf blades. The lesions have a chevron pattern of light (tan) and darker reddish-brown areas (Fig. 6-17). The leading edge of the lesion usually is yellow to gold (Fig. 6-18). Fields look yellow or gold. Lesions from the edges of leaf blades have an indistinct, mottled pattern. Affected leaves dry and turn straw-colored.

Fig. 6-18. Leaf scald.

Panicle infestations cause a uniform light to dark, reddish-brown discoloration of entire florets or hulls of developing grain. The disease can cause sterility or abortion of developing kernels. Control measures are not recommended, but foliar fungicides used to manage other diseases have activity against this disease.

Leaf Smut

Leaf smut, caused by the fungus *Entyloma oryzae*, is a widely distributed, but somewhat minor, disease

Fig. 6-19. Leaf smut.

of rice. The fungus produces slightly raised black spots (sori) on both sides of the leaves (Fig. 6-19) and on sheaths and stalks. The blackened spots are about 0.5 to 5.0 mm long and 0.5 to 1.5 mm wide. Many spots can be found on the same leaf, but they remain distinct from each other. Heavily infected leaves turn yellow, and leaf tips die and turn gray. The fungus is spread by airborne spores and overwinters on diseased leaf debris in soil. Leaf smut occurs late in the growing season and causes little or no loss. Control measures are not recommended.

Narrow Brown Leaf Spot

Narrow brown leaf spot, caused by the fungus *Cercospora janseana*, varies in severity from year to year and is more severe as rice plants approach maturity. Leaf spotting may become very severe on the more susceptible varieties and causes severe leaf necrosis. Premature ripening, yield reduction and reduced milling can occur. The disease is most severe on ratoon crop rice.

Fig. 6-20. Narrow brown leaf spot.

Symptoms include short, linear, brown lesions most commonly found on leaf blades (Fig. 6-20). Symptoms also occur on leaf sheaths, pedicels and glumes. Leaf lesions are 2 to 10 mm long and about 1 mm wide, tend to be narrower, shorter and darker brown on resistant varieties and wider and lighter brown with gray necrotic centers on susceptible varieties. On upper leaf sheaths, symptoms are similar to those found on the leaf. On lower sheaths, the symptom is a "net blotch" or spot in which cell walls are dark brown and intracellular areas are tan to yellow (Fig. 6-21).

Fig. 6-21. Net blotch phase of narrow brown leaf spot.

The primary factors affecting disease development are (1) susceptibility of varieties to one or more prevalent pathogenic races, (2) prevalence of pathogenic races on leading varieties and (3) growth stage. Although rice plants are susceptible at all stages of growth, the plants are more susceptible from panicle emergence to maturity. Differences in susceptibility among rice varieties are commonly observed, but resistance is an unreliable control method as new races develop readily. Some fungicides used to reduce other diseases also may have activity against narrow brown leaf spot. Low N levels favor development of this disease.

Root Knot

Species of the nematode *Meloidogyne* cause root knot. Symptoms include enlargement of the roots and the

Fig. 6-22. Root knot.

formation of galls or knots (Fig. 6-22). The swollen female nematode is in the center of this tissue. Plants are dwarfed, yellow and lack vigor. The disease is rare and yield losses low. The nematode becomes inactive after prolonged flooding. No control measures are recommended.

Root Rot

Root rots are caused by several fungi, including *Pythium spinosum*, *P. dissotocum*, other *Pythium* spp. and several other fungi. The rice plant is predisposed to this disorder by a combination of factors, including physiological disorders, insect feeding, especially feeding of rice water weevil larvae, extreme environmental conditions and various other pathogens.

Symptoms can be noted as early as emergence. Roots show brown to black discoloration and necrosis (Fig. 6-23). As the roots decay, nutrient absorption is disrupted, the leaves turn yellow and the plants lack vigor. With heavy root infections, plants lack support from the roots and lodge, causing harvest problems. Often, plants with root rot show severe brown leaf spot infection. The disease is referred to as feeder root necrosis when the small fine roots and root hairs are destroyed on seedling and young plants. When this happens, no lodging occurs and symptom development is not as apparent on the upper plants.

Fig. 6-23. Root rot.

Fertilizer usually reduces the aboveground symptoms although actual nutrient use is impaired. Rice water weevil control greatly reduces root rots. Draining fields stimulates root growth but can cause problems with blast, weeds or efficiency of nutrient use.

Seedling Blight

Seedling blight, or damping off, is a disease complex caused by several seed-borne and soil-borne fungi, including species of *Cochiobolus*, *Curvularia*, *Sarocladium*, *Fusarium*, *Rhizoctonia* and *Sclerotium*. Typically, the rice seedlings are weakened or killed by the fungi. Environmental conditions are important in disease development. Cold, wet weather is most favorable to disease development.

Seedling blight causes stands of rice to be spotty, irregular and thin. Fungi enter the young seedlings and either kill or injure them. Blighted seedlings that emerge from the soil die soon after emergence. Those that survive generally lack vigor, are yellow or pale green and do not compete well with healthy seedlings.

Severity and incidence of seedling blight depend on three factors: (1) percentage of the seed infested by seed-borne fungi, (2) soil temperature and (3) soil moisture content. Seedling blight is more severe on rice that has been seeded early when the soil is usually cold and damp. The disadvantages of early seeding can be partially overcome by seeding at a shallow depth. Conditions that tend to delay seedling emergence favor seedling blight. Some blight fungi that affect rice seedlings at the time of germination can be reduced by treating the seed with fungicides.

Seeds that carry blight fungi frequently have spotted or discolored hulls, but seed can be infected and still appear to be clean. *Cochiobolus miyabeanus*, one

Fig. 6-24. Seedling blight.

of the chief causes of seedling blight, is seed-borne. A seedling attacked by this fungus has dark areas on the basal parts of the first leaf (Fig. 6-24).

If rice seed is sown early in the season, treating the seed is likely to mean the difference between getting a satisfactory stand or having to plant a second time. Little benefit is received from treating rice seed to be sown late in the season, unless unfavorable weather prevails.

The soil-borne seedling blight fungus, *Sclerotium rolfsii*, kills or severely injures large numbers of rice seedlings after they emerge when the weather at emergence is humid and warm. A cottony white mold develops on the lower parts of affected plants. This type of blight can be checked by flooding the land immediately.

Treatment of the seed with a fungicide is recommended to improve or ensure stands. Proper cultural methods for rice production, such as proper planting date or shallow seeding of early planted rice, will reduce the damage from seedling blight fungi.

Water- and soil-borne fungi in the genus *Pythium* attack and kill seedlings from germination to about the three-leaf stage of growth. Infected roots are discolored brown or black, and the shoot suddenly dies and turns straw-colored. This disease is most common in water-seeded rice, and the injury is often more visible after the field is drained. It may also occur in drill-seeded rice during prolonged wet, rainy periods.

Seed treatment, planting when temperatures favor rapid growth of seedlings and draining the field are the best management measures for seedling disease control.

Sheath Blight

Sheath blight has been the most economically significant disease in Louisiana since the early 1970s. The disease is caused by *Rhizoctonia solani*, a fungal pathogen of both rice and soybeans. On soybeans, it causes aerial blight.

Several factors have contributed to the development of sheath blight from minor to major disease status. They include the increased acreage planted to susceptible long-grain varieties, the increase in the acreage of rice grown in rotation with soybeans, the increased use of broadcast seeding and the higher rates of N fertilizers used with the modern commercial rice varieties. The disease is favored by dense stands with a heavily developed canopy, warm temperature and high humidity. The fungus survives between crops as structures called sclerotia or as hyphae in plant debris. Sclerotia (Fig. 6-25) or plant debris floating

Fig. 6-25. Sheath blight sclerotia on stem.

Fig. 6-26. Sheath blight lesions on sheath.

Fig. 6-27. Sheath blight lesions on leaves.

on the surface of irrigation water serves as sources of inoculum that attack and infect lower sheaths of rice plants at the waterline.

Sheath blight is characterized by large oval spots on the leaf sheaths (Fig. 6-26) and irregular spots on leaf blades (Fig. 6-27). Infections usually begin during the late tillering-joint elongation stages of growth. Lesions about 0.5 to 1 cm in width and 1 to 3 cm in length are formed a little above the waterline on infected culms (Fig. 6-28). Fungus mycelium grows up the leaf sheath, forms infection structures, infects and causes new lesions. The infection can spread to leaf blades. The lower leaf sheaths and blades are affected during the jointing stages of growth. After the panicle emerges from the boot, the disease progresses rapidly to the flag leaf on susceptible varieties. With very susceptible varieties, the fungus will spread into the culm from early sheath infections. Infected culms are weakened, and the tillers may lodge or collapse.

The fungus can spread in the field by growing from tiller to tiller on an infected plant or across the surface of the water to adjacent plants. The fungus also grows across touching plant parts, for example from leaf to leaf, causing infections on nearby plants. Infected plants are usually found in a circular pattern in the field because the fungus does not produce spores and must grow from plant to plant.

Fig. 6-28. Early, intermediate and late sheath blight lesions.

The lesions have grayish-white or light green centers with a brown or reddish-brown margin. As lesions coalesce on the sheath, the blades turn yellow-orange and eventually die. As areas in the field with dead tillers and plants increase, they may coalesce with other affected areas to cause large areas of lodged, dead and dying plants. Damage is usually most common where wind-blown, floating debris accumulates in the corners of cuts when seedbeds are prepared in the water.

Sheath blight also affects many grasses and weeds other than rice, causing similar symptoms. Sclerotia that survive between crops are formed on the surface of lesions on these weed grasses, as well as on rice and soybeans. The sclerotia are tightly woven masses of fungal mycelium covered by an impervious, hydrophobic coating secreted by the fungus.

Disease severity can be reduced by integrating several management practices. Dense stands and excessive use of fertilizer both tend to increase the damage caused by this disease. Broadcast seeding tends to increase stand and canopy density. Rotation with soybeans or continuous rice increases the amount of inoculum in field soils. Fallow periods, with disking to control growth of grasses, will reduce inoculum in the soil.

The pathogen also is known to infect sorghum, corn and sugarcane when environmental conditions are favorable for disease development.

Medium-grain rice varieties are more resistant to sheath blight than most of the long-grain varieties. Several recently released long-grain varieties are more resistant to sheath blight than the older long-grain varieties (see LSU AgCenter publication 2270, "Rice Varieties and Management Tips").

Fungicides are available for reducing sheath blight. Ask an Extension Agent for the latest information on fungicides for sheath blight management.

Sheath Blotch

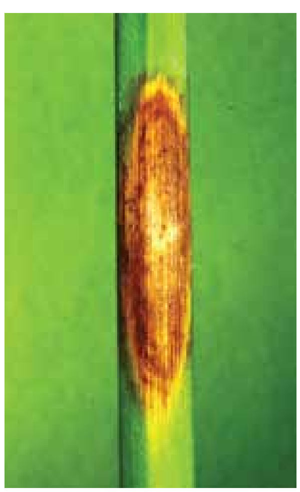


Fig. 6-29. Sheath blotch.

This fungal disease affects the leaf sheaths, especially the flag-leaf sheath near the collar. The lesion usually starts at an edge of the sheath and enlarges to form an oblong blotch that may increase in size until it covers the sheath, but the lesion is usually restricted and becomes zonate (Fig. 6-29). This distinguishes it from sheath rot caused by *Sarocladium oryzae*. Many black fruiting structures (pycnidia) are visible in the lesion. This disease is normally not severe or widespread enough to warrant control measures.

Sheath Rot

This disease is caused by the fungal pathogen *Sarocladium oryzae*. Symptoms are most severe on the uppermost leaf sheaths that enclose the young panicle during the boot stage. Lesions are oblong or irregular oval spots with gray or light brown centers and a dark reddish-brown, diffuse margin (Fig. 6-30), or the lesions may form an irregular target pattern. On U.S. rice varieties, the lesion is usually expressed as a reddish-brown to purple-brown discoloration of the flag leaf sheath. Early or severe infections affect the panicle so that it only partially emerges. The unemerged portion of the panicle rots, turning florets to dark brown. Grains from damaged panicles are discolored reddish-brown to dark brown and may not fill. A powdery white growth consisting of spores and hyphae of the pathogen may be observed on the inside of affected sheaths. Insect or mite damage to the boot or leaf sheaths increases the damage from this disease.

Fig. 6-30. Sheath rot.

This disease affects most rice varieties. The disease is usually minor, affecting scattered tillers in a field. Occasionally, larger areas of a field may have significant damage. Control measures are not recomvmended. Fungicidal sprays used in a general disease management program reduce damage, but recent studies show that several bacterial pathogens commonly cause similar sheath rot symptoms on rice in Louisiana. Fungicides would have little effect on these pathogens.

Sheath Spot

This disease is caused by the fungus *Rhizoctonia oryzae*. The disease resembles sheath blight but is usually less severe. The lesions produced by *R. oryzae* are found on sheaths midway up the tiller or on leaf blades (Fig. 6-31). Lesions are oval, 0.5 to 2 cm long and 0.5 to 1 cm wide. The center is pale green, cream or white with a broad, dark reddish-brown margin (Fig. 6-31). Lesions are separated on the sheath or blade and do not form the large, continuous lesions often found with sheath blight. The pathogen attacks and weakens the culm under the sheath lesion on very susceptible varieties. The weakened culm lodges or breaks over at the point where it was infected. Lodging caused by sheath spot usually occurs midway up the culm. This disease is usually minor on Louisiana rice. Some fungicides used to manage sheath blight also reduce sheath spot.

Fig. 6-31. Sheath spot lesions.

Stackburn

This disease was first observed on rice growing in Louisiana and Texas. Stackburn or Alternaria leaf spot is caused by the fungal pathogen *Alternaria padwickii*. It is common on rice around the world.

The disease is present in most rice fields in Louisiana. Only occasional spots are observed, but the disease may be more severe in restricted areas of a field. The spots are typically large (0.5- to 1-cm in diameter), oval or circular, with a dark brown margin or ring around the spot (Fig. 6-32). The center of the spot is initially tan and eventually becomes white or nearly white. Mature spots have small dark or black dots in the center. These are sclerotia of the fungus. Grain or seeds affected by the disease have tan to white spots with a wide, dark brown border. The disease causes discoloration of kernels or the kernels stop development and grains are shriveled.

Fig. 6-32. Stackburn.

This fungus is the most common seed-borne fungus in Louisiana and may cause seedling blight. It is more common on panicles and grain than on leaves in Louisiana.

No specific control recommendations are available, but seed-protectant fungicides will help reduce the seedling blight caused by this pathogen and will reduce the number of spores available to cause leaf infections.

Stem Rot

Stem rot, caused by the fungus *Sclerotium oryzae*, is an important disease in Louisiana. Often, losses are not detected until late in the season when it is too late to initiate control practices. Stem rot causes severe lodging, which reduces combine efficiency, increases seed sterility and reduces grain filling.

The first symptoms are irregular black angular lesions on leaf sheaths at or near the water line on plants at tillering or later stages of growth (Fig. 6-33). At later stages of disease development, the outer sheath may die and the fungus penetrates to the inner sheaths and culm. These become discolored and have black or dark brown lesions. The dark brown or black

Fig. 6-33. Stem rot lesion.

Fig. 6-34. Stem rot scerotia.

streaks have raised areas of dark fungal mycelium on the surface and gray mycelium inside the culm and rotted tissues. At maturity, the softened culm breaks, infected plants lodge and many small, round, black sclerotia develop in the dead tissues (Fig. 6-34).

The pathogen overwinters as sclerotia in the top 2 to 4 inches of soil and on plant debris. During water-working and establishment of early floods, the hydrophobic sclerotia float on the surface of the water and often accumulate along the edge of the field and on levees because of wind action.

After a permanent flood is established, the sclerotia float to the surface, contact the plant, germinate and infect the tissues near the waterline. The fungus then penetrates the inner sheaths and culm, often killing the tissues. The fungus continues to develop, forming many sclerotia in the stubble after harvest.

Most commercial varieties of rice are not highly resistant to stem rot. The disease is favored by high N levels. Early maturing varieties are usually less affected by stem rot. In addition, applications of K fertilizer reduce disease severity in soils where K is deficient. Stem rot is more serious in fields that have been in rice production for several years.

Suggested management measures include using early maturing varieties, avoiding very susceptible varieties, burning stubble or destroying by cultivation after harvest to destroy sclerotia, using crop rotation when possible, applying K fertilizer, avoiding excessive N rates and using foliar fungicides recommended by the LSU AgCenter.

Water Mold and Seed Rot

When using the water-seeding method of planting rice, it is difficult to obtain uniform stands of sufficient density to obtain maximum yields. The most important biological factor contributing to this situation is the water mold or seed rot disease caused primarily by fungi in the genera *Achlya* and *Pythium*. Recently, certain *Fusarium* spp. also have been found associated with molded seeds. The disease is caused by a complex of these fungi infecting seeds. The severity of this disease is more pronounced when water temperatures are low or unusually high. Low water temperatures slow the germination and growth of rice seedlings but do not affect growth of these pathogens. In surveys conducted in Louisiana during the 1970s and 1980s, an average of 45 percent of water-planted seeds was lost to water mold.

In addition to the direct cost of the lost seeds and the cost of replanting, water mold also cause indirect losses through the reduced competitiveness of rice with weeds in sparse or irregular stands. Also, replanting or overseeding the field causes the rice to mature late when conditions are less favorable for high yields because of unfavorable weather and high disease pressure.

Fig. 6-35. Water mold.


Fig. 6-36. Water mold caused by Achlya.


Fig. 6-37. Water mold caused by Pythium

Water mold can be observed through clear water as a ball of fungal strands surrounding seeds on the soil surface (Fig. 6-35). After the seeding flood is removed, seeds on the soil surface are typically surrounded by a mass of fungal strands radiating out over the soil surface from the affected seeds. The result is a circular copper-brown or dark green spot about the size of a dime with a rotted seed in the center (Fig. 6-36). The color is caused by bacteria and green algae, which are mixed with the fungal hyphae.

Achlya spp. (Fig. 6-35) normally attack the endosperm of germinating seeds, destroying the food source for the growing embryo and eventually attacking the embryo. *Pythium* spp. (Fig. 6-37) usually attack the developing embryo directly. When the seed is affected by the disease, the endosperm becomes liquified and oozes out as a white, thick liquid when the seed is mashed. The embryo initially turns yellow-brown and finally dark brown. If affected seeds germinate, the seedling shoot and roots are attacked by *Pythium* spp. after the seedling is established, the plant is stunted, turns yellow and grows poorly. If the weather is favorable for plant growth, seedlings often outgrow the disease and are not severely damaged.

The disease is less severe in water-seeded rice when weather conditions favor seedling growth. Temperatures averaging above 65 degrees F favor seedling growth, and water mold is less severe. Seeds should be vigorous and have a high germination percentage. Seed with poor vigor will be damaged by water mold fungi when water seeded.

Treat seed with a recommended fungicide at the proper rate to reduce water molds and seed diseases. A list of recommended fungicides is available through LSU AgCenter extension agents. Most rice seed is treated by the seedsman and is available to the grower already treated. Seed-protectant fungicides differ in their effectiveness. Information on recent results from seed-protectant fungicide trials can be obtained from an extension agent or the Rice Research Station. In field tests, these fungicides have increased stands over those produced by untreated seeds from 25 to 100 percent.

White Leaf Streak

White leaf streak is caused by the fungal pathogen *Mycovellosiella oryzae*. The symptoms are very similar to the narrow brown leaf spot symptoms caused by *Cercospora janseana* except that the lesions are slightly


Fig. 6-38. White leaf streak symptoms.

wider with white centers (Fig. 6-38). The disease is common on leaf blades some years but is not severe enough to warrant control measures.

White Tip

This disease is caused by the nematode *Aphelenchoides besseyi*. Characteristic symptoms that appear after tillering include the yellowing of leaf tips, white areas in portions of the leaf blade (Fig. 6-39), stunting of affected plants, twisting or distortion of the flag leaf and distortion and discoloration of panicles and florets. Leaf tips change from green to yellow and eventually white. The tip withers above the white area, becoming brown or tan and tattered or twisted. Resistant varieties may show few symptoms and still have yield loss. The nematode infects the developing grain and is seed-borne. This disease is present endemically in Louisiana but is considered a minor rice disease. Fumigation of seeds in storage may reduce the nematode population. No other specific control measures are recommended.

Fig. 6-39 White tip.

Scouting and management practices recommended for major rice diseases

BACTERIAL PANICLE BLIGHT

Scouting and Determining Need

Florets on young panicles become discolored and stay upright as the floret is sterile or aborts. Floret stems (panicle branches) stay green after the unaffected grain matures. Damage may vary from a single floret to all of the florets on a panicle. Damage is most severe during periods of unusually hot weather or unusually hot nights.

Management Practices

Most commercial varieties are susceptible, but some show significant partial resistance. The pathogens are seed-borne and the pathogenic bacteria remain on leaves throughout the vegetative stages of the rice plant without showing symptoms. Panicles become infected as they emerge. No pesticides are currently recommended to control this disease. The best control measure is to not plant seed from fields that were seriously affected the previous year. A procedure has been developed to test seed lots for the pathogen and to quantify the pathogen. This procedure is not yet widely available. Avoiding excessive N rates and early planting can reduce disease.

BLAST

Scouting and Determining Need

Varieties with low levels of resistance should be scouted for leaf blast during the vegetative stages of growth. Leaf blast is more likely when the flood is lost, excessive N is used or rice is planted late in the growing season. Sandy soils and tracts near tree lines are areas where blast is likely to occur. Rotten neck blast has no predictive systems. Since significant damage is already done when rotten neck or panicle blast is first detected, preventive sprays are required on susceptible varieties when blast has been detected in the area.

Management Practices

Plant varieties resistant to blast. Avoid late planting. Plant as early as possible within your recommended planting period. For leaf blast, reflood if field has been drained. Maintain flood at 4 to 6 inches. Do not overfertilize with N. Apply a fungicide if necessary. Contact your parish LSU AgCenter extension agent for the latest information on available fungicides and timing.

SHEATH BLIGHT

Scouting and Determining Need

Fields should be scouted for the presence of sheath blight symptoms at least once a week beginning at midtillering and continuing until heading. The field should be scouted by making periodic random stops throughout the field. Tillers should be examined for the presence of symptoms. When 5 to 10 percent of the tillers of a susceptible variety or 10 to 15 percent of the tillers of a moderately susceptible variety are infected, a fungicide application is justified.

Management Practices

Avoid dense stands and excessive N fertilizer. Most long-grain varieties have little resistance to sheath blight. Medium-grain varieties are more resistant. Timing and rate of fungicide applications are critical for good sheath blight management. Check with your parish LSU AgCenter extension agent for the latest information on fungicides. Fallow periods, with disking to control grasses in the field (which serve as sources of inoculum) and break down crop residue, help reduce disease pressure.

BROWN SPOT

Scouting and Determining Need

Disease is most severe when plants are N deficient or under other stresses. Plants become more susceptible as they approach maturity.

Management Practices

Maintain good growing conditions through proper fertilizer, land leveling, good soil preparation and other cultural practices. Use recommended seed protectant fungicides to reduce inoculum. Correct stress conditions in the field. All varieties are susceptible but some more than others.

NARROW BROWN LEAF SPOT

Scouting and Determining Need

Disease is most severe from panicle emergence to maturity. Several pathogenic races are present, and new races develop to affect resistant varieties.

Management Practices

Some commercial varieties have acceptable levels of resistance to this disease. See LSU AgCenter publication 2270, “Rice Varieties and Management Tips Publication.” Check with your parish LSU AgCenter extension agent for latest information on the use of available fungicides. Apply fungicides at the recommended rate and timing.

STEM ROT

Scouting and Determining Need

Most commercial varieties are susceptible. Infection takes place at the water line, and angular black lesions form. The number of infected tillers may reach 100 percent in areas of the field where debris and sclerotia from the previous crop have collected after being windblown on the water surface.

Management Practices

Applying K will reduce disease severity where K is deficient. Early maturing varieties are less affected by stem rot. Destroying the sclerotia in stubble by crop rotation, tillage or burning can reduce disease pressure.

WATER MOLD AND SEED ROT

Scouting and Determining Need

The fungi causing this disease are soil- and waterborne. They occur in most rice fields. The seed rot and water mold diseases are most severe under flooded conditions when the water is cold.

Management Practices

Seed should be treated with recommended fungicides. Check with your parish LSU AgCenter extension agent for recent information on effective seed-protectant fungicides. Draining the seeding flood and flushing as needed helps prevent water mold. The practice of pinpoint flooding helps reduce water mold damage. Seeding should not begin until the mean daily temperature reaches 65 degrees F.

SEEDLING BLIGHT

Scouting and Determining Need

The fungi causing this disease can be seed-borne or soil-borne. They are common and normally are present on seeds or in soil. Seedling blight is common in drill-seeded or dry- broadcast rice.

Management Practices

Treating seed with seed-protectant fungicides effectively reduces seedling blight. Check with your parish LSU AgCenter extension agent for recent information on effective seed-protectant fungicides.

GRAIN SPOTTING AND PECKY RICE

Scouting and Determining Need

Since grain spotting and pecky rice diseases are normally associated with insect damage, scout for the rice stink bug. Monitor fields from immediately after pollination until kernels begin to harden. Sample with a sweep net and count the number of insects collected. Refer to LSU AgCenter publication 2270, "Rice Varieties and Management Tips" for current stinkbug control recommendations.

Management Practices

Control of the stink bugs with insecticides is the only management measure for grain spotting and pecky rice.

KERNEL SMUT, FALSE SMUT

Scouting and Determining Need

No scouting is possible since disease does not appear until heading and control is ineffective after this stage.

Management Practices

Excessive N increases diseases. Some varieties have resistance. Boot applications of certain fungicides reduce disease.

LEAF SMUT, SHEATH ROT, SHEATH SPOT, LEAF SCALD, STACKBURN, ROOT ROT, ROOT KNOT, WHITE TIP, PANICLE BLIGHT, DOWNY MILDEW, BACTERIAL LEAF BLIGHT, BLACK KERNEL, CROWN ROT, CROWN SHEATH ROT, SHEATH BLOTCH, WHITE LEAF STREAK

Scouting and Determining Need

These diseases rarely occur with enough severity to warrant control measures or scouting.

Management Practices

Control measures are not available or recommended for these diseases. Varieties differ in their reaction to these diseases, but extensive evaluations have not been conducted.

Fungicides used to manage other major diseases reduce several of these diseases. Check with your parish LSU AgCenter extension agent for the latest information.

Chapter 7

Invertebrate Pest Management

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The major invertebrate pests of rice in Louisiana are the rice water weevil and the rice stink bug. In addition, rice stem borers, rice seed midge, the rice leaf miner, the South American rice miner, and armyworms can be important rice pests. The panicle rice mite has recently been reported in rice fields in the state. The panicle rice mite is an arachnid and not an insect. Under heavy infestation levels, all of these pests can cause economic losses. This section contains information about the identification, life cycle, injury to rice and current scouting and management practices for these pests. The scouting and management recommendations are based on the best available information and will be modified as additional research is conducted. If you suspect insect injury in your field(s), contact your county agent for verification and help with insect management and damage assessment.

The preferred approach to controlling insect pests is by developing and following an integrated pest management plan. IPM is the integration of a variety of pest control strategies to effectively maintain a pest insect population at densities below the economic threshold for treatment. An effective integrated pest management plan relies on knowledge of the important pest species attacking the crop and utilization of a variety of control tactics. These tactics can include cultural practices, application of insecticides, biological control and breeding for resistance. The use of a variety of control strategies can result in a more effective and less expensive control program. Cultural control strategies include such practices as water and weed management. Resistant rice varieties may have the ability to tolerate insect infestations or may be more difficult for insects to feed and develop on. The use of insecticides with varying modes of action remains a vital component of the management program for most rice pests, but use of insecticides and miticides ideally should be limited because insecticides disrupt natural controls, can affect nontargets and are expensive. In addition, if an insecticide is used repeatedly within a season, insects can develop resistance to this product, making it ineffective for controlling insects. To avoid the development of resistance, it is important to use a variety of means to control insects. The products, which are discussed in this section, have varying levels of toxicity to crawfish and extreme caution should be used when controlling insects in rice fields which are near crawfish ponds.

The first step in effective integrated pest management is to properly identify the insect attacking the crop. Once the pest has been identified, it is important to develop an understanding of the life cycle of the pest and how it damages the crop. Finally, a well-thought-out plan must be developed to effectively manage the pest while continuing to utilize best management practices. For this reason, it is very important to be familiar with your field and what complex of diseases, insects and weeds exists in the particular agro-ecosystem.

Rice Water Weevil

Lissorhoptrus oryzophilus Kuschel

Description and Life Cycle

The rice water weevil is the most important early season insect pest of rice in Louisiana. Adults of this insect emerge from overwintering sites beginning in early April in southern Louisiana (later in northern Louisiana) and fly to rice fields, where they feed on young rice leaves. This form of injury is not economically important except under unusually heavy infestations or prolonged cold springs when rice grows slowly. Egg-laying commences when standing water is present in a field that is infested with adults. This condition is usually met immediately after a permanent flood is applied to a field. Young rice is preferred for oviposition. After eclosing from eggs, larvae feed under water on rice roots and pass through four larval instars and a pupal stage in approximately 30 days.

Fig. 7-1. Adult rice water weevil.

The rice water weevil is the most injurious insect pest in Louisiana rice production. Yield losses in excess of 25 percent can occur from severe infestations.

Rice water weevil adults are grayish-brown weevils (beetles) about 1/8 inch long with a dark brown V-shaped area on their backs (Fig. 7-1). Rice water weevils overwinter as adults in grass clumps and ground debris near rice fields and in wooded areas. A degree day model based on historical records of weevil emergence from overwintering was recently developed to predict adult emergence. According to this model, emergence from overwintering sites usually begins in the first 2 weeks of April in southwestern Louisiana. Adults emerging from overwintering will invade either unflooded or flooded rice fields and begin feeding on the leaves of rice plants. One key aspect of the biology of female rice water weevils is that females do not lay many eggs until fields are flooded. In unflooded fields, females may lay eggs in areas of fields that contain standing water, such as low spots, potholes or tractor tire tracks. Application of the permanent flood is a trigger for females to lay numerous eggs in leaf sheaths of rice plants. Females deposit white, elongate eggs in the leaf sheath at or below the waterline. In addition to laying eggs in rice, adult rice water weevils will oviposit (lay eggs) in most aquatic grasses and sedges, including barnyard grass, fall panicum, red rice, yellow nutsedge and broadleaf signalgrass. Thus, the presence of these weeds on levees surrounding rice fields may make the fields more susceptible to attack by rice water weevil adults.

White, legless, c-shaped larvae with small brown head capsules emerge from eggs in about 7 days. First instar larvae are about 1/32 inch long and feed in the leaf sheath for a short time before exiting the stem and falling through the water to the soil, where they burrow into the mud and begin feeding on the roots of rice plants (Fig. 7-2). The larvae continue to feed in or on the roots of rice plants and weeds in and around the field developing through four instars in about 27 days. Larvae increase in size with each succeeding molt. Fourth instar larvae are about 3/16 inch long. Larvae pupate in oval, watertight cocoons attached to the roots of rice and weed plants. The cocoons are covered with a compacted layer of mud and resemble small mud balls (Fig. 7-3). Peak larval density occurs 3 to 5 weeks after flooding.

Fig. 7-2. Rice water weevil larva (root maggot).

Adults emerge from the cocoons and are able to fly a short time after emerging and may return to overwintering sites or attack a different rice field. Newly emerged adult weevils usually do not re-infest the same field that they emerge from because they prefer to attack young plants. The life cycle from egg to adult takes about 30 days. The length of the life cycle is temperature-dependent, however, and can vary from 25 to 45 days in warm and cool weather, respectively. The number of generations per year varies with latitude. As many as three to four generations can occur in the southern rice-growing areas of Louisiana.

Fig. 7-3. Rice water weevil pupae.

Fewer generations occur in the northern rice-growing areas.

Injury

Fig. 7-4. Rice water weevil feeding scars.

Adult rice water weevils feed on the upper surface of rice leaves, leaving narrow longitudinal scars that parallel the midrib (Fig. 7-4). Adult feeding can kill plants when large numbers of weevils attack very young rice, but this is rare and is usually localized along the field borders. Most economic damage is caused by larvae feeding in or on rice roots. Under heavy infestation, the root systems of affected plants can be severely damaged (Fig. 7-5). This feeding or root pruning results in reduction in the number of tillers and in the amount of aboveground plant material produced by the damaged plant. Root pruning may interfere with nutrient uptake by plants. Damage to roots ultimately can result in yield losses by decreasing panicle densities, numbers of grains per panicle, and grain weights. Plants with severely pruned root systems (Fig. 7-5) may turn yellow and appear to be N deficient. Infested stands are often thin in appearance and are more susceptible to lodging. At harvest, plants from heavily infested fields will be shorter than normal and have lower yields. Each larva found in a 4-inch (diameter) by 3-inch (deep) core sample is associated with an approximately 0.5 to 1.5 percent loss in yield. Yield losses tend to be higher in water-seeded rice fields. Losses are higher because these fields are usually flooded at an earlier stage of plant growth and thus are susceptible to oviposition and infestation by larvae earlier. Young rice plants are more susceptible to yield losses than are older plants with more established root systems.

Fig.7-5. Heavily pruned roots (left) versus healthy roots (right).

All currently grown rice varieties are susceptible to the rice water weevil. Recent research, however, indicates some differences in varietal susceptibility. Medium-grain varieties appear to be more susceptible to infestation than long-grain varieties.

Scouting and Management Using Insecticides

A variety of cultural and chemical controls can control rice water weevils in rice fields. Cultural strategies include planting rice early in the season rather than late, delaying the application of permanent flood and perhaps managing weeds in and around rice fields. Insecticide management practices for the rice water weevil are evolving as pesticides are added to and removed from the integrated pest management plan. These insecticides fall into three general categories: (1) prophylactic seed treatments, (2) early postflood adulticides and (3) larvicides. For the most current list of registered pesticides, please consult LSU AgCenter publications 1838 (“Pest Management Guide”) and 2270 (“Rice Varieties and Management Tips”).

Adult Monitoring and Management

Adulticides include liquid and granular formulations of insecticides. The timing of application of foliar and granular applications of insecticides to control adults is crucial, and more than one application may be required. Oviposition is possible when standing water is present in a field, i.e. when the field has been saturated by rainfall or flushing or when permanent flood has been established. In most fields, the majority of oviposition is likely to occur after the establishment of permanent flood. To apply an adulticide at the optimum time for adult weevil control, scout for adults immediately after application of the permanent flood. To scout for weevil adults, check at least five to 10 locations per field for the presence of adults or their feeding scars. Treat when adult weevils or their scars are observed and conditions for egg laying are favorable as described above. Applications made 24 hours before initiation of permanent flood also can be effective when adults are present in unflooded fields and feeding scars are visible. More than one application of insecticide may be required because residual activities of most insecticides appear to be less than 1 week and weevils will continue to invade the field. Be sure to follow label instructions for limitations on the number of insecticide applications allowed in one season and the preharvest interval. Once fields have been treated, begin sampling again after 7 days.

The goal of the use of adulticidal insecticides is to reduce larval infestations by killing adults before they lay eggs. Once eggs are laid in rice leaf sheaths or larvae are in the roots, these insecticides will not be effective. Applications of adulticides for the control of eggs or larvae are ineffective. Work on managing rice water weevil using foliar insecticides is ongoing. As insecticides are added to and removed from the market, recommendations for the management of the rice water weevil with foliar insecticides may change.

Applications of granular formulations of adulticides are an alternative method that minimizes insecticide drift into nontarget areas (such as crawfish ponds). These formulations will only control adults and are to be used in a manner identical to that described above for liquid formulations of adulticides. Similarly, pyrethroids impregnated on fertilizer will kill adults but will not kill larvae feeding on roots.

Larval Monitoring and Management

Larvicidal compounds are insecticides that target larval rice water weevils after they have established on the roots of rice plants. Carbofuran (Furadan) was a widely used example of this type of insecticide. Carbofuran is no longer registered for use in rice fields, but larvicidal insecticides may become available in the future. Larvicidal insecticides should be applied when densities of larvae exceed three larvae per core. The numbers of larvae on rice roots peak 3 to 5 weeks after application of permanent flood. At this time, many of the larvae will be large, and a significant amount of root pruning will have occurred. Larvicidal compounds should be applied before larval populations reach their peak. Early scouting

Fig. 7-7. Rice water weevil sampling bucket.

of fields (10 to 20 days after flooding) can indicate if and when larvicidal treatment is required to prevent damaging infestations.

To scout for rice water weevil larvae, take the first larval count 10 to 14 days after establishment of the permanent flood in a drill-seeded system. At least six sites should be randomly selected in each field. At each site, remove a single core of plants and soil 4 inches in diameter and 3 inches deep and place it in a 10-quart bucket with a 40-mesh screen bottom (Fig. 7-7). Wash the soil from the plant roots through the screen bottom in the bucket by thoroughly stirring the soil in the water. Push the bucket up and down vigorously in the water several times. This forces water up through the screen bottom and helps to separate larvae from any plant debris remaining in the bucket. After a few seconds, larvae will float to the surface where they can be counted and removed. Repeat the washing procedure several times to make sure all larvae in a sample have been counted. If larvae are not found in any sample, sample the field again in five to 7 days. If the average number of larvae per sample is fewer than five, sample the field again 3 to 5 days later. If the average number of larvae per sample is five or more, the field should be treated with available larvacides or drained. Sampling should cease when the field has been treated or when plants have reached the 2-mm panicle stage of development.

Prophylactic Seed Treatments

With this method of control, the insecticide is applied directly to the seed. Depending on the type of insecticide, either larval or adult control may occur. Scouting is not required with this method since it is used as a preventative treatment. Effectiveness of prophylactic seed treatment, however, should be assessed by monitoring larval populations using the bucket sampling method described above.

Management Using Cultural Control

Three primary cultural control strategies can be used to augment use of insecticides to control rice water weevils. The first cultural control strategy is early planting of rice. Early planting has multiple advantages. The first advantage is that populations of rice water weevil adults infesting early planted fields are generally smaller than populations that infest later-planted fields. This is true because emergence from overwintering sites occurs over a long window of time and the population is not fully emerged when rice is planted early. More weevils are present in late-planted rice fields because they are infested by weevils both from overwintering sites and surrounding rice fields. The second advantage of early planting is the plants are infested at a later stage of development, when they are more tolerant to injury and less susceptible to oviposition. Adults prefer to oviposit on young rice plants.

Fig. 7-8. Rice stink bug adults.

Another cultural control strategy is draining fields to reduce rice water weevil larvae numbers. Soil must dry to the point of cracking. Draining fields is the only rice water weevil control method available for rice grown in rotation with crawfish. Draining fields for rice water weevil control requires careful planning so conflicts with weed, disease and fertilizer management programs can be avoided or minimized. Moreover, draining may not effectively kill larvae if rainfall prevents soil from drying until "cracking."

Finally, delaying the application of permanent flood can substantially reduce the amount of damage caused to your crop by rice water weevils. On average, 10 percent greater yield losses were observed in early flooded rice plots compared with yield losses in field in which flooding was delayed by 2 weeks.

Rice Stink Bug

Oebalus pugnax (F.)

Description and Life Cycle

Adult rice stink bugs are shield-shaped, metallic-brown insects about 1/2 inch long (Fig. 7-8). Rice stink bugs overwinter as adults in grass clumps and ground cover. They emerge from overwintering sites in early spring and feed on grasses near rice fields before invading fields of maturing rice. They are particularly attracted to rice during the flowering stage. Adults live 30 to 40 days. Females lay masses of light green cylindrical eggs on the leaves, stems and panicles of rice plants. Eggs are laid in parallel rows with about 20 to 30 eggs per mass (Fig. 7-9). As they mature, eggs become black with a red tint. Immature stink bugs (nymphs) emerge from eggs in

Fig. 7-9. Rice stink bug hatchling (first instar nymphs).

Fig. 7-10. Rice stink bug nymph.

4 to 5 days in warm weather or as long as 11 days in cool weather. Nymphs develop through five instars in 15 to 28 days. Newly emerged nymphs are about 1/16 inch long, with a black head and antennae and a red abdomen with two black bars (Fig. 7-9). Nymphs increase in size with successive molts, and the color of later instars becomes tan-green (Fig. 7-10).

Injury

Nymphs and adults feed on the rice florets and suck the sap from developing rice grains. Feeding on florets and on grains in the early milk stage can reduce rough rice yields; however, most economic loss results from reductions in grain quality that results from stink bugs feeding on developing kernels. Pathogens enter the grain at the feeding spot and the pathogen infection and bug feeding together cause discolored and pecky rice kernels. Discolored or "pecky" rice kernels have lower grade and poor milling quality (Fig. 7-11). Both adult and nymph rice stink bugs feed on developing rice grains, but adults alone account for most economic losses in rice. Relationships between stink bugs and stink bug injury show a strong increase in percentage of pecky rice and a strong decrease in percentage of head yield with increasing numbers of adult stink bugs during the heading period.

Fig. 7-11. Pecky rice, stink bug damage.

Scouting and Management

Several natural enemies are important in reducing rice stink bug numbers in rice. Adults and nymphs are parasitized by the flies, *Beskia aelops* (Walker) and *Euthera tentatrix* Lav. Rice stink bug eggs are parasitized by the tiny wasps, *Oencyrtus anasae* (Ashm.) and *Telonomus podisi* (Ashm.). Management relies significantly on the activity of these naturally occurring biological control agents. Insecticidal control based on the results of field scouting is recommended when rice stink bugs escape from the control provided by natural enemies.

Rice fields should be sampled for stink bugs using a 15-inch diameter insect sweep net once each week beginning immediately after pollination and continuing until kernels harden. Do not sample fields at midday when stink bugs may be seeking shelter from the heat in the shade at or near the ground. Avoid sampling field borders, where stink bug numbers are often higher than in the field interiors. A sample consists of 10 consecutive 180 degree sweeps made while walking through the field. Hold the net so that the lower half of the opening is drawn through the foliage. After 10 successive sweeps, count the number of rice stink bug nymphs and adults. Normally, 10 samples of 10 sweeps each are made per field. Alternatively, 100 random sweeps may be taken per field. During the first 2 weeks of heading, fields averaging one or more rice stink bugs per three sweeps (30 or more per 100 sweeps) should be treated with an insecticide. After the first 2 weeks of heading, treat fields when an average one or more stink bugs per sweep (100 or more per 100 sweeps) is found. Do not treat fields within 2 weeks of harvest. Contact your parish LSU AgCenter extension agent for specific treatment recommendations. Please consult LSU AgCenter publications 1838 ("Pest Management

Guide") and 2270 ("Rice Varieties and Management Tips") for the most current list of pesticides registered to control rice stink bugs.

Stem Borers

The rice crop in Louisiana can be attacked by the European corn borer, rice stalk borer, sugarcane borer and Mexican rice borer. The sugarcane borer and the rice stalk borer are increasingly important pests of rice in Louisiana. In addition, the European corn borer has been reported affecting localized rice fields in northern parts of the state. A fourth stem borer, the Mexican rice borer, is present in Texas. Two adult males were trapped in Louisiana in 2008. It is likely this borer will become a pest of rice in Louisiana. Increased adoption of minimum tillage and several years of mild and dry winters contributed to the growth of borer populations. In addition, corn, sorghum and rice fields frequently lie in close proximity to one another and are sequentially planted in the northern half of the state. This creates an array of suitable host crops available for the development and expansion of borer populations throughout the growing season. Rice is susceptible to economic injury from panicle differentiation through the dough stage. Yield loss in rice results from plant tunneling, lodging, "deadhearts," "whiteheads" and "partial whiteheads."

The sugarcane borer and the rice stem borer are distributed statewide. Both species overwinter as last instar larvae in the stalks of rice and other weedy host plants. For this reason, the stubble should be plowed to remove the overwintering habitat. These larvae pupate in the spring, and adult moths emerge during early May.

Sugarcane Borer

Diatrea saccharalis (F.)

Description and Life Cycle

The sugarcane borer is the most aggressive and economically important stem borer that attacks rice in some central and northeastern Louisiana rice areas. Sugarcane borers overwinter as last instar larvae in the stalks of rice and other weedy plants. These larvae pupate in the spring, and adult moths emerge as early as May, mate and live on various hosts until rice stem

Fig. 7-12. Sugarcane borer adult.

Fig. 7-13. Sugarcane borer egg mass.

diameter is large enough to support larval feeding. Adult sugarcane borers are straw-colored moths about 3/4 inch long with a series of black dots, arranged in an inverted V-shape pattern, on the front wings (Fig. 7-12). Egg-laying on rice can begin as early as May, but economically damaging infestations generally do not occur until July through September. The flat, oval, cream-colored eggs are laid at night in clusters of two to 100 on the upper and lower leaf surfaces over 1 to 6 days (Fig. 7-13). Larvae emerge in 3 to 5 days, crawl down the leaf and bore into the plant stem. They move up and down the stem, feeding for 15 to 20 days before chewing an exit hole in the stem and pupating. Larvae are pale yellow-white in the summer, with a series of brown spots visible on the back (Fig. 7-14). Overwintering larvae are a deeper yellow and lack the brown spots. The lack of stripes


Fig. 7-14. Sugarcane borer larva.


Fig. 7-15. Sugarcane borer pupa.

distinguishes sugarcane borer larvae from rice stalk borer larvae, which have stripes in the winter and summer. Mature larvae are about 1 inch long and do not enclose themselves in a silken web before pupation. The pupae are brown, about 1 inch long and roughly cylindrical in shape, not smoothly tapered as are rice stalk borer pupae (Fig. 7-15). Overwintering sugarcane borer larvae are usually found closer to the plant crown than rice stalk borer larvae. The pupal stage lasts 7 to 10 days. There are three generations per year.

Rice Stalk Borer

Chilo plejedellus (Zink)

Description and Life Cycle

The rice stalk borer is a sporadic pest of rice in Louisiana. Rice stalk borers overwinter as last instar larvae in the stalks of rice and other host plants. Larvae pupate in the spring, and adult moths emerge in early to late June, mate and live on various hosts until rice stem diameter is large enough to support tunneling larvae. Adults are about 1 inch long with


Fig. 7-16. Rice stalk borer adult.


Fig. 7-17. Rice stalk borer larva.

pale white fore and hind wings tinged on the edges with metallic gold scales. Front wings are peppered with small black dots (Fig. 7-16). Although egg laying may begin in late May, injurious infestations usually occur from August through September. Flat, oval, cream-colored eggs are laid in clusters of 20 to 30 on the upper and lower leaf surfaces. Eggs are laid at night over 1 to 6 days. Larvae emerge in 4 to 9 days and crawl down the leaf toward the plant stem. Larvae may feed for a short time on the inside of the leaf sheath before boring into the stem. Larvae of the rice stalk borer are pale yellow-white with two pairs of stripes running the entire length of the body and have a black head capsule (Fig. 7-17). These stripes distinguish rice stalk borer larvae from sugarcane borer larvae, which have no stripes. Mature larvae are about 1 inch long. Larvae move up and down the stem feeding for 24 to 30 days before moving to the first joint above the waterline, chewing an exit hole in the stem and constructing a silken web in which to pupate. Pupae are about 1 inch long, brown and smoothly tapered. The pupal stage lasts 7 to 10 days. There are two to three generations per year in rice.

Fig. 7-18. European corn borer adult.

Fig. 7-19. European corn borer larva.

European Corn Borer

Ostrinia nubilalis (Hübner)

Description and Life Cycle

The European corn borer may increase their population densities in corn and grain sorghum before migrating to rice fields. They have the potential for severe infestations in rice in central and northern latitudes of Louisiana. Adult European corn borers have delta-shaped wings with wavy dark lines running across them (Fig. 7-18). Adults infest the crop, and the lifecycle is very similar to sugarcane borer or rice stalk borer. Larvae of the European corn borer have a flesh-colored body that may have a grayish, greenish or pinkish tinge (Fig. 7-19). Spots run the length of the body and may be the same color as the body. It has two distinct light brown spots on the top of each abdominal segment and a distinctive mid-dorsal dark band. The head capsule is reddish to black.

Fig. 7-20. Mexican rice borer adult.

Fig. 7-21. Mexican rice borer larva.

Mexican Rice Borer

Eoreuma loftini (Dyar)

Description and Life Cycle

The Mexican rice borer is a devastating pest of sugarcane and a serious rice pest. Basic life cycle biology of the Mexican rice borer has been studied mainly on sugarcane, which has suffered from severe infestations in Texas. Mexican rice borer moths are light tan with delta-shaped wings (Fig. 7-20). Adult moths lay spherical, cream-colored eggs in groups of five to 100. Young larvae feed on the tissue inside the leaf sheath and quickly migrate from the oviposition site to bore into the rice stem after about one week of feeding. Larvae are honey-colored with two pairs of stripes running the length of the body (Fig. 7-21). Pupation takes place inside the rice stem after mature larvae have constructed an emergence window covered by one or two layers of plant tissue.

Fig. 7-22. Dead heart caused by Mexican rice borer.

Fig. 7-23. White head.

Injury

Injury to rice results from stem borer larvae feeding on plant tissue as they tunnel inside the stem. Injury is often first noticed when the youngest partially unfurled leaf of the plant begins to wither and die, resulting in a condition called dead-heart (Fig. 7-22). Later in the growing season, these rice stems are weakened and may lodge before harvest. Stem feeding that occurs during panicle development causes partial or complete sterility and results in the white-head condition (Fig. 7-23). The white, empty panicles are light in weight and stand upright.

Scouting and Management

Scouting for stem borers should start at green ring and must be intensified as plants get closer or reach early boot stages. Scouts should look for feeding lesions located on the inside surface of the leaf sheath (Fig. 7-24). These lesions are caused by the larva that

Fig. 7-24. Borer damage at collar of leaf.

feeds underneath the leaf sheath during the 2 or 3 days before it bores into stems. These feeding lesions are easily observed from the outside. Care must be taken, however, to avoid confusing these lesions with those caused by sheath blight. Peel off the leaf sheath to expose the feeding larva or to detect the presence of frass to ensure it is the stem borer and not sheath blight damage (Fig. 7-25). In addition, scouts must look for adults, egg masses or fresh feeding scars on the leaves.

Fig. 7-25. Borer feeding on stem behind leaf sheath.

Unfortunately, by the time signs of field infestations (deadhearts, white-heads) are noted, it is usually too late to apply effective insecticides. For insecticides to be effective, application must coincide with larval emergence so small larvae are killed before they enter rice stalks. Once larvae enter the stalks, insecticides are not effective. Extensive scouting of rice fields is required to time insecticide applications properly. Scouting can be conducted for stem borer adults or egg masses. Eggs are laid over an extended period, however, and although some injury may be prevented, satisfactory control using insecticides is difficult and generally has not been successful. Please consult LSU AgCenter publications 1838 (“Pest Management Guide”) and 2270 (“Rice Varieties and Management Tips”) for the most current list of insecticides labeled to control borers in rice.

Biological control can sometimes be effective to control stem borers. Stem borer eggs and larvae are parasitized by the wasps, *Trichogramma minutum* Riley and *Agathis stigmaterus* (Cresson), respectively. It is believed these parasites play an important role in maintaining stem borer numbers below economic levels.

The most effective means for reducing overwintering borer populations is areawide destruction of crop residues after harvest. For this to be effective, plant stubble must be destroyed close to or below the soil surface. Crop rotation is not an effective tool for managing borers because the field-to-field mobility of moths allows them to infest newer areas. Pheromone traps are useful for monitoring the emergence and movement of the European corn borer and Mexican rice borer, but no pheromone is currently available to monitor sugarcane borer moths. Therefore, plant inspections still are needed to detect sugarcane borer infestations. Early planting is also important for rice grown near corn in areas with a history of borer infestations. Early planting allows those crops to mature before the beginning of moth migration from maturing corn fields. No economic thresholds have been developed for these insects in rice. Please consult your parish LSU AgCenter extension agent for the latest recommendations to control stem borers in rice.

Fig. 7-26. Seed midge swarms.

Fig. 7-27. Midge tubes on soil under water.

Fig. 7-28. Seed midge damage.

Rice Seed Midge

Chironomus spp.

Description and Life Cycle

Adult midges can be seen in swarms over rice fields, levees, roadside ditches and other bodies of water (Fig. 7-26). Adult midges resemble small mosquitoes but lack the needlelike mouthparts and hold their forelegs up when resting. Elongate eggs are laid in strings, usually on the surface of open water. The strings are held together by a sticky material that forms a gelatinous coat around the eggs. After emerging, the larvae move to the soil surface, where they live in spaghetti-like tubes constructed from secreted silk, plant debris and algae. The larvae mature through four instars before pupating under water in the tubes (Fig. 7-27). The life cycle from egg to adult requires 10 to 15 days.

Injury

Larvae injure rice by feeding on the embryo of germinating seeds (Fig. 7-28) or on the developing roots and seeds of very young seedlings. Midge injury occurs in water-seeded rice and is usually not important once seedlings are several inches tall. The potential for midge injury increases when fields are flooded far in advance of water-seeding rice. Water-seeded fields should be scouted for midge injury, checking for hollowed out seed within 5 to 7 days after seeding. Injury from the midge can be insignificant (not economically important) to very severe. Injury can also be localized, making damage assessment difficult. In some instances, whole fields may need to be replanted. In other instances, only parts of fields may require reseeding.

Scouting and Management

Rice seed midge is a problem only for rice seeds and seedlings in water-seeded fields. Midges are not a problem in rice more than 2 to 4 inches tall. Scout fields for midges and midge injury within 5 to 7 days after seeding. Repeat scouting at five- to seven-day intervals until rice seedlings are about 3 inches tall. Midge presence is indicated by larval tubes on the soil surface. There are many midge species, most of which do not attack rice, and the presence of midge tubes alone does not indicate the need to treat a given field.

Midge injury is indicated by the presence of chewing marks on the seed, roots and shoots and by the presence of hollow seeds (Fig. 7-28). If midge injury is present and plant stand has been reduced to fewer than 15 plants per square foot, treatment may be necessary.

Rice seed midge management includes chemical and cultural control options. One cultural management option is to drain fields to reduce numbers of midge larvae. Reseeding of heavily infested fields may be necessary. The potential for damaging levels of seed midge can be reduced or prevented by using recommended water and crop management practices. Holding water in rice fields for more than 2 to 3 days before seeding encourages the buildup of large midge numbers before seeding and should be avoided. Practices that encourage rapid seed germination and seedling growth, such as using presprouted seed and avoiding planting in cool weather, will help to speed rice through the vulnerable stage and reduce the chance for serious damage.

Rice Leaf Miner

Hydrellia griseola

Description and Life Cycle

Adult flies have clear wings on a metallic blue-green-to-gray thorax (Fig. 7-29). Less than 1/4 inch long, they can be seen flying close to the water and landing on rice leaves. They lay eggs singly on rice leaves. Eggs are laid on seedlings before application of permanent floodwater. After application of permanent flood, white eggs are laid singly on leaves that float on the floodwater. Transparent or cream-colored legless larvae emerge in 3 to 6 days and begin feeding between the layers of the rice leaf. Larvae become yellow to light green as they feed. Mature larvae are about 1/4 inch long (Fig. 7-30). The larvae feed for 5 to 12 days before pupating. Adults emerge after 5 to 9 days and live 2 to 4 months. Under ideal conditions, the life cycle can be completed in as few as 15 days. In cool weather, the life cycle can extend for more than one month.

Fig. 7-29. Adult leaf miner.

Fig. 7-30. Rice leaf miner larva.

Injury

The rice leaf miner is a sporadic problem in Louisiana. Rice is attacked in the early spring, and infestations usually occur on the upper side of levees

Fig. 7-31. Rice leaf miner damage in fields where water is more than 6 inches deep.

Fig. 7-32. Bumps in leaves indicate leaf miners.

Fig.7-33. Rice leaf miner pupa.

where water is deepest. Rice leaf miner is not usually a problem in water 4 to 6 inches deep. Problems are more severe in continuously flooded rice than in periodically flooded rice and when water is more than 6 inches deep. Larvae tunnel between the layers of the leaf, attacking and killing leaves closest to the water. Larvae move up the plant, killing additional leaves, and under heavy infestations the entire plant may die, reducing stands severely (Fig. 7-31). In Louisiana, rice leaf miner seems to attack fields in the same vicinity year after year.

Scouting and Management

Scout fields for rice leaf miners by walking through flooded rice fields and gently drawing the leaves of rice plants between the thumb and forefinger. Bumps in the leaves indicate the presence of leaf miner larvae or pupae (Fig. 7-32). The larvae or pupae can be found by separating the layers of the leaf (Fig. 7-33). If leaf miners are present and plant numbers are reduced to less than 15 per square foot, treatment is necessary. Rice leaf miner management involves cultural control or insecticide application, perhaps both. Maintaining water depth at 4 to 6 inches will usually prevent problems with rice leaf miner. If leaf miners are present, lowering the water level in rice fields so that rice leaves can stand up out of the water also will help to prevent injury. Contact your parish LSU AgCenter extension agent for specific control recommendations.

South American Rice Miner

Hydrellia wirthi Korytkowski

Description and Life Cycle

The South American rice miner (SARM) is an invasive insect pest of rice in the United States. It is a close relative of the rice leaf miner, which is widely distributed across U.S. rice fields. Current SARM distribution places this insect across the most important rice areas of Louisiana and Texas. SARM adults are small, gray to dark gray flies of about 1/10 inch in length. SARM eggs are elongated, ribbed, white or creamy-white and approximately 0.5 mm long and 0.2 mm wide (Fig. 7-34). Eggs are laid singly on the upper surface of rice leaves, near the leaf margins. Larvae are small, white or yellowish legless maggots of approximately 1/4 inch in length (Fig. 7-35). The puparium is elongate, tapered at both ends and brown (Fig. 7-36).

Fig. 7-34. SARM egg.

Fig. 7-35. SARM maggot.

Fig. 7-36. SARM pupa.

Injury

Economic injury to rice plants tends to occur in young rice from emergence until the tillering stages, particularly in late-planted fields (planted in May and June in central and southwest Louisiana). Injury is caused by the larva or maggot, which causes large, elongated lesions along the margins of emerging leaves. The maggot mines the leaf or rasps the leaf surface before the leaf unfurls. As the leaf expands, yellow damaged areas are more visible (Fig. 7-37). Affected young leaves usually break off or display a ragged appearance. The maggot continues to feed on the whorl tissue and enters the stem of developing plants. Because of the damage to the whorl of rice plants, the SARM also is termed “whorl maggot” by several rice producers. It is common to find more

Fig. 7-37. SARM or "whorl maggot" damage.

than one maggot in a single stem. Affected seedling plants are killed or their growth is severely retarded. Pupation occurs inside the affected stem, near the collar of the leaf. Field damage is distributed in large patches either in the center or along the margins of the field (Fig. 7-38).

Scouting and Management

Scout young rice for large, elongated lesions along the margins of emerging leaves. If you suspect a SARM infestation, contact your parish LSU AgCenter extension agent for damage assessment and to obtain the latest developments on this insect pest.

Fig. 7-38. SARM field damage.

Fig. 7-39. Chinch bugs on rice.

Chinch Bug

Blissus leucopterus leucopterus (Say)

Description and Life Cycle

Chinch bugs overwinter as adults in grass clumps, leaf litter and other protected areas, emerging in early to mid-spring to feed and mate on grass hosts, including small grains such as wheat, rye, oats and barley. Adults are small, black insects about 1/6 inch long, with white front wings (Fig. 7-39). Each wing has a triangular black spot near the outer wing margin. Adults lay white, elongated eggs 1/24 inch long behind the lower leaf sheaths or in the soil near the root. Eggs turn red as they mature and larvae emerge in 7 to 10 days. There are five nymphal instars. Early instar nymphs are red with a yellow band on the front part of the abdomen (Fig. 7-40). Last instar nymphs are black and gray with a conspicuous white spot on the back (Fig. 7-41). The

Fig. 7-40. Early instar nymph of Chinch bug on rice.

Fig. 7-41. Late instar nymphs and adult chinch bugs.

life cycle from egg to adult takes 30 to 40 days, and adults may live 2 to 3 weeks.

Injury

Chinch bugs are a sporadic pest of rice in Louisiana. They tend to be more of a problem in drill-seeded rice because of the delayed application of permanent flood. Economic injury to rice generally occurs when favorable weather conditions and production practices allow chinch bugs to build in corn, sorghum and wheat fields. As these crops mature and are harvested, large numbers of chinch bugs may move to young plants in nearby rice fields. Serious economic losses have resulted from chinch bug infestations in north and south Louisiana. The trend toward increasing acreage of small grains increases the potential for chinch bug problems. Chinch bug injury results when adults and nymphs feed on the leaves and stems of rice plants. Feeding on young seedlings causes leaves and stems to turn light brown (Fig. 7-42). High numbers of chinch bugs can kill young plants, severely reducing plant stands.

Scouting and Management

Check unflooded rice near small grain fields or recently cut grassy areas every 3 to 5 days from seedling emergence until application of permanent flood. Check foliage in rice fields for chinch bugs. During warm weather, chinch bugs will hide in cracks at the soil line. Young nymphs can be found feeding on roots. Thresholds for chinch bugs in rice are not available. If high numbers of chinch bugs are present and plant stands are being reduced, the field should be treated. Cultural and chemical control methods are available. Cultural control consists of flooding infested fields to kill chinch bugs or to force them to move onto rice foliage where they can be treated with an insecticide. This tactic requires that levees be in place and that rice plants be sufficiently large to withstand a flood. Cultural control may be more expensive than chemical control. Contact your parish LSU AgCenter extension agent for specific recommendations if chemical control is needed.

Fig. 7-42. Firing of lower leaves from chinch bugs.

Fall Armyworm

Spodoptera frugiperda (J. E. Smith)

Description and Life Cycle

The fall armyworm feeds on most grasses found in and around rice fields. It is also a serious pest of corn and pasture grasses. Since rice is not its preferred host, the fall armyworm is only an occasional pest on rice. Adult moths are about 1 inch long with gray-brown sculptured front wings and whitish hind wings (Fig. 7-43). The front wings of male moths have a white bar near the wing tip. This bar is absent in female moths. Females lay masses of 50 to several hundred whitish eggs on the leaves of rice and other grasses in and around rice fields. Egg masses are covered with moth scales and appear fuzzy. The larvae emerge in 2 to 10 days, depending on temperature, and begin feeding on rice plants. They vary from light green to brown to black but have distinctive white stripes along the side and back of the body

Fig. 7-43. Fall armyworm adult.

Fig. 7-44. Fall armyworm larvae.

Fig. 7-45. Mature larvae have a distinctive inverted "Y" on the head capsule.

(Fig. 7-44). Larvae feed for 2 to 3 weeks, developing through four instars. Mature larvae are about 1 inch long and have a distinctive inverted "Y" on the head (Fig. 7-45). Mature larvae prepare a cocoon and pupate in the soil or decomposing plant material. Moths emerge in 10 to 15 days, mate and disperse widely before laying eggs on new plants. At least four generations per year occur in Louisiana.

Injury

Fall armyworm larvae feed on the leaves of young rice plants, destroying large amounts of tissue. When large numbers of armyworms are present, seedlings can be pruned to the ground, resulting in severe stand loss. Fall armyworm infestations generally occur along field borders, levees and in high areas of fields where larvae escape drowning. The most injurious infestations occur in fields of seedling rice that are too young to flood. Larvae from the first overwintering generation, occurring in early spring, are the most injurious. Infestations later in the season may cause feeding injury to rice panicles, although this is rare.

Scouting and Management

After germination of seedlings, scout fields weekly for larvae on plants. Sample plants every 10 feet along a line across the field, and repeat this process in a second and third area of the field. Treat when there is an average of one armyworm per two plants. Fall armyworm management consists of cultural, chemical and biological control. Naturally occurring populations of parasitic wasps and pathogenic microorganisms frequently reduce armyworm numbers below damaging levels. Since adults lay eggs on grasses in and around rice fields, larval infestations can be reduced by effective management of grasses. When fall armyworm numbers reach threshold levels, cultural or chemical control is needed. Cultural control consists of flooding infested fields for a few hours to kill fall armyworm larvae. This requires that levees be in place and that rice plants be large enough to withstand a flood. Cultural control may be more expensive than chemical control. Contact your parish LSU AgCenter extension agent for specific recommendations if chemical control is needed.

Panicle Rice Mite

Steneotarsonemus spinki Smiley

Description and Life Cycle

The panicle rice mite (PRM), *Steneotarsonemus spinki* Smiley, has recently been reported in the continental United States. The panicle rice mite is a pest of commercial rice production in Asia, India, Central America and the Caribbean. Significant crop losses have been attributed to this mite, particularly in the presence of sheath rot and bacterial panicle blight. The adult PRM are clear to straw-colored, oval and

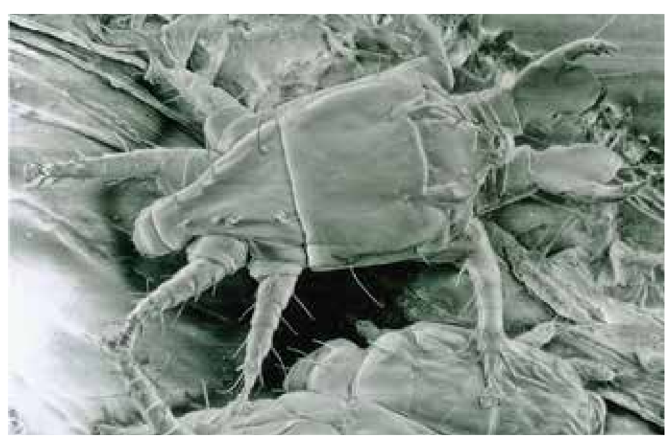


Fig. 7-46. Adult panicle rice mite. (USDA photo)

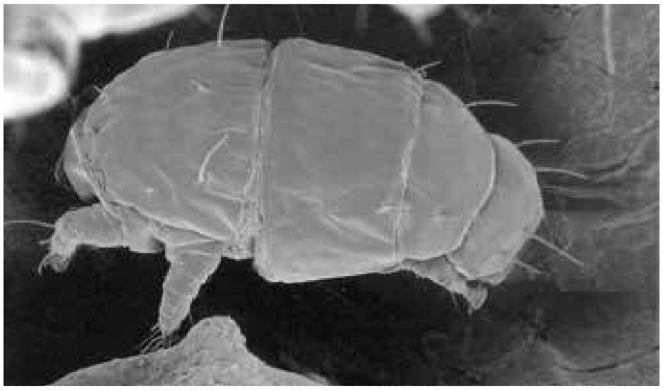


Fig. 7-47. Immature panicle rice mite. (USDA Photo)

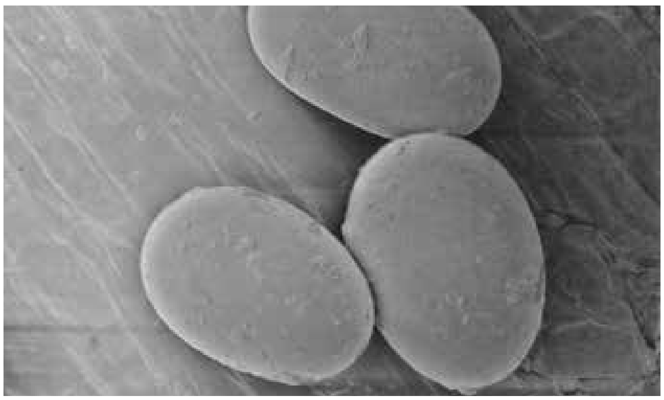


Fig. 7-48. Panicle rice mite eggs. (USDA Photo)

approximately 1/100 of an inch long (Fig. 7-46). Immature PRM are clear to straw-colored and about ½ the size of adults (Fig. 7-47). Eggs are clear in color, oval-shaped and about one-third the size of adults (Fig. 7-48). An entire lifecycle can be completed in 7 to 21 days, depending on temperature.

Injury

The PRM injures rice plants both directly by feeding on cells of rice leaves, stems and kernels and indirectly by vectoring and/or facilitating the establishment of fungal, bacterial and possibly viral pathogens. Feeding damage can result in a sterile grain syndrome, which is described as a loose and brownish flag leaf sheath, a twisted panicle neck, impaired grain development with empty or partially filled grains with brown spots and panicles standing erect. Extensive reports from important rice-producing areas of the world attribute yield losses to the interaction between the PRM and *Burkholderia glumae*, the causal agent of bacterial panicle blight, and the fungus *Sarocladium oryzae*, which is the causal agent of sheath rot and one of the many important contributors to kernel spotting ("pecky" rice). Injury to de-

Fig. 7-49. Panicle rice mite injury.

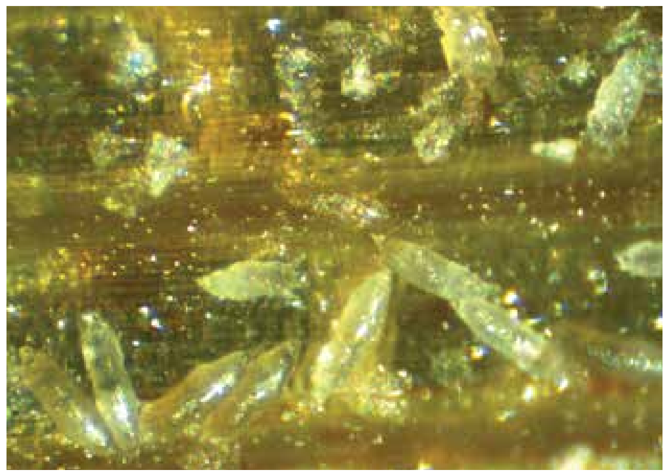


Fig. 7-50. Panicle rice mites on sheath.

veloping grains leads to panicle sterility. Malformed grains sometimes show a curved appearance, often referred to as "parrot-beak" symptom. Damage to the leaf sheath reduces the photosynthetic potential of the plant and can have a negative effect on fertility. The heaviest and most economically damaging populations of PRM are often reported during the second or ratoon crop.

Scouting and Management

Scout for PRM by looking for the symptoms associated with bacterial panicle blight and sheath rot. In affected plants, look for a cinnamon, yellow or chocolate-brown discolored lesion on the leaf sheath that does not have a distinct edge (Fig. 7-49). To find mites, pull the leaf sheath back and examine the underside of the leaf sheath with a minimum 20X hand-lens. The PRM feeds on the plant material on the inside of the flag leaf sheath (Fig. 7-50). Once a new leaf begins to develop, a female PRM will move to the new leaf sheath, produce male offspring and establish a new feeding lesion. Thus, damage will often be observed on interior sheaths when the outer sheath is removed. This continues until the PRM reaches the leaf nearest the stem. They also feed on developing panicles from the boot stage to the milk stage of heading.

Contact your parish LSU AgCenter extension agent if you suspect that this mite may be present in your field and to obtain the latest information on this pest.

Colaspis

Colaspis brunnea and *Colaspis louisianae*

There are two species of colaspis that can be found in Louisiana rice: *Colaspis brunnae* and *Colaspis louisianae*. This pest can be found damaging fields of dry-seeded rice in a soybean-rice rotation. In Arkansas, damage from this pest is typically more severe in light textured soils. The damage is often concentrated in high spots in the field.

Description and Life Cycle

Colaspis will complete a single generation in soybeans and lespedeza. This is why they are often called Lespedeza worms. The larvae of colaspis will overwinter in the soil (Fig. 7-51). When rice, or another

Fig. 7-51. Colaspis larva.

Fig. 7-52. Colaspis pupa.

Fig. 7-53. Colaspis adult.

Fig. 7-54. Rice field damage caused by colaspis larvae feeding on roots.

crop, is planted into a field that is infested with colaspis larvae, the larvae will begin to feed on the roots of the plant. Feeding on fine root hair may result in plant death. The larvae will then pupate (Fig. 7-52) and emerge as adults. Adults are oval in shape and about ¼ inch in length. They are a light golden color with white/gold stripes down the back and long antennae (Fig. 7-53). Adults will not lay eggs on rice, but will most likely travel to a nearby soybean field. It is common to find a clumped distribution of larvae in the soil and patches of stand loss (Fig. 7-54).

Scouting

To scout for this pest, locate plants that are stunted, dying and surrounded by declining plants. The plants will often appear to be withering and drying. Dig around the base of the plants, carefully peeling back the soil and looking for white grubs with brown heads that are a little larger than RWW larvae. You may also find pupae or adults in the soil.

Management

We do not have any insecticides labeled to control colaspis in Louisiana rice. The only thing we can recommend is to apply permanent flood as soon as possible. These insects are not aquatic and so they cannot survive in a permanent flood. This is why they are not reported as a problem in water-seeded rice.

Amaurochrous dubius
(formerly called Black Rice Bugs)

Both nymphs (Fig. 7-55) and adults (Fig. 7-56) cause damage by feeding with their piercing mouthparts. Feeding on the leaf sheath can cause dead or dying leaves, usually lower leaves, in otherwise healthy rice. The damaged leaves will often have a yellow, orange or red coloration (Fig. 7-57). Adults are related to the more traditional stink bugs as evidence by their odor when disturbed. These bugs are sometimes called turtle bugs. Neither the term Black Rice Bug nor Turtle Bug is the correct common name for this insect.

Fig. 7-55. Amaurochrous dubius nymph

Fig. 7-56. Amaurochrous dubius adult

Fig. 7-57. Amaurochrous dubius rice damage.

Fig. 7-58. Southern green stinkbug.

Fig. 7-59. Billbug grub.

Fig. 7-60. Billbug adults.

Fig. 7-61. Skipper adult.

Fig. 7-62. Skipper larva.

Other Insect Pests of Rice

Several other insects may occasionally attack rice in Louisiana. They include the southern green stink bug, *Nezara viridula* (L.) (Fig. 7-58), rice levee bill bug (Figs. 7-59 and 7-60), several grasshopper species and the larvae of several species of skippers (Figs. 7-61 and 62) and tiger moths. The numbers of these insects in rice fields are usually below levels justifying treatment, but they may increase rapidly under favorable conditions and yield losses can occur. Contact your parish LSU AgCenter extension agent for specific treatment recommendations.

Stored Grain Pests of Rice

Rice that is stored as seed or grain for consumption may be susceptible to attack by grain pests. These include beetles and moths. The most important pests of stored rice in Louisiana are the lesser grain borer (Fig. 7-63), the rice weevil (Fig. 7-64), the Angoumois grain moth (Fig. 7-65) and the Indian meal moth (Fig. 7-66). The lesser grain borer and the Angoumois grain moth larva bore into the kernels and destroy them whereas the rice weevil attacks those kernels with broken hulls. Other insects of lesser importance that may be found in rice bins include the saw-toothed grain beetle, the red flour beetle, flat grain beetle, cigarette beetle and the Mediterranean flour moth. These insects infest secondarily, feeding mostly on broken kernels, flour and on the frass of the lesser grain borer and the other insects that bore directly into whole kernels.

The first step in control of stored grain pests is to thoroughly clean storage bins. Good sanitation may prevent infestation of stored grain and decrease cost by preventing the need for fumigants. Both old and new bins should be prepared in the same manner. The bins should be thoroughly cleaned at least 2 weeks prior to storing grain. To properly clean bins, all old grain, trash and debris should be removed from within the storage bin and fumigated or burned. Brush away all debris (including spider webs) attached to the sides of the bin and wash the inside and outside surfaces of the bin with a high-pressure hose. Be sure to remove all grain from cracks and crevices. Any grain left in the cracks can increase your chance of infestation by stored grain pests.

After the bin is clean, it should be treated with an insecticide. Spray the bin inside and out (including overhead) with a labeled insecticide. Consult LSU AgCenter publication 1838, "Insect Pest Management Guide," for currently labeled insecticides for treating bins. Treat the wall surfaces and any cracks and crevices. Be sure to follow all label instructions when applying any insecticides. The pH of the tank water should be adjusted using a buffering adjuvant as necessary. For best results, the tank water should be slightly acidic with a pH of 5.5 to 6.5. You may want to consider applying a grain protectant to rice that will be stored. This action may prevent early infestation of stored grain. Grain must be at the proper moisture content for storage prior to application. DO NOT apply the grain protectant before high-temperature drying. If rice is already infested with a grain pest (at the time of harvest), it must be fumigated before storage. If your rice becomes infested with a stored grain pest while it is being stored in a bin, fumigation is the only option of treatment. Check publication 1838, "Insect Pest Management Guide," for the latest fumigation registrations. Be sure to follow label instructions for application method, rate and insects to treat. The bin must be closed a minimum of 4 days during fumigation.

Fig. 7-63. Lesser grain borer. (Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org)

Fig. 7-64. Rice weevil. (Joseph Berger, Bugwood.org)

Fig. 7-65. Angumois grain moth. (Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org)

Fig. 7-66. Indian meal moth. (Joseph Berger, Bugwood.org)

Chapter 8

Rice Drying on the Farm

Dennis Gardisser and Johnny Saichuk

Drying and storing rice on the farm can be an excellent marketing strategy. The way that rice is handled during the drying and storage process will determine its quality at the point of sale, thereby influencing its value.

Rice should be quickly dried down to a moisture level of about 12 percent for storage, especially if it is going to be stored for several months. The reduction of grain moisture is done by passing relatively large quantities of dry air over the rice after it is place in the bin. The quality and quantity of this air determines the final moisture content of the rice kernel.

Air quality is typically referred to as the equilibrium moisture content (EMC). It is the combination of temperature and relative humidity at which rice will not gain or lose moisture from the air. If the air has an EMC of 12 percent, the grain moisture will eventually reach 12 percent if air of that quality is moved over the grain long enough.

The EMC may be determined by measuring air temperature and relative humidity. Relative humidity is determined by measuring wet bulb and dry bulb temperatures and comparing these values with a table. Relative humidity is a measure of how much moisture is in the air at a given temperature in comparison with how much it could hold at that same temperature. At 100 percent relative humidity, the air is holding all of the moisture it is capable of holding at that temperature. The actual amount of moisture capable of being held varies with air temperature. Hot air holds more water than cold air. Wet bulb and dry bulb temperatures are measured by using a device called a sling psychrometer. This device has two identical thermometers, but the bulb of one is covered with a cloth sack that is moistened when it is used. The thermometers are mounted on a board or similar structure that permits them to be slung through the air. The wet bulb temperature will be lower than the dry bulb as a result of evaporative cooling.

In drying rice, maintaining a steady EMC as close to the target storage moisture (12 or 13 percent) content is important. Usually, there are many days during and shortly after the harvest season when the EMC is at or below the desired level without adding any heat. At night or during damp weather conditions, it may be necessary to add some heat to condition the air to a desirable EMC or to maintain the same level available during the daylight hours. If heat is not available, it may be better to turn the fans off at night instead of pumping in moist air. Moist air that is pumped in at night has to be removed later. This increases drying cost and may result in significant head rice yield reduction. 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.

A given volume of air has the capability of holding a given amount of moisture. That amount will depend on the quality. One way to increase drying potential or cause the grain to reach equilibrium with the air sooner is to pass larger amounts of air over the grain. Doubling air flow typically cuts the drying time in about one-half. 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. Recommended minimum airflow rates for different moisture contents are:

13 to 15% moisture	1 to 2 CFM per cwt
15 to 18% moisture	4 CFM per cwt
18 to 20% moisture	6 CFM per cwt
20 to 22% moisture	8 CFM per cwt
22 % moisture and above	12 CFM per cwt

As grain bins are filled and the grain depth increases, it becomes more difficult to pass air up through the grain. As the grain depth increases, less air is available for each bushel of grain in the bin. High volumes of air are needed to carry the moisture away in

Fig. 8-1. Axial flow fan.

Fig 8-2. Centrifugal fan.

Fig 8-3. Blades of centrifugal fan.

a timely fashion when the grain is at high moisture levels. Most on-farm bins have a limited amount of available air capacity.

The grain drying industry offers basically two types of drying fans, the centrifugal and axial flow fans. From these two types, manufacturers provide a number of variations 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.

The axial fan utilizes a propeller wheel mounted directly to the motor shaft; thus, it develops a very high tip speed and is often noisy (Fig. 8-1). Some axial fans incorporate air straightening vanes to increase efficiency and increase static pressure. The normal upper limit of static pressure of an axial fan is about 5 inches of water. Axial fans are cheaper and are most often used where high airflow rates at low static pressures are needed.

Centrifugal fans provide a relatively constant air volume over a wide range of static pressures with a practical limit of 9 to 10 inches of water (Fig. 8-2). Higher static pressures can be obtained with special design; however, the 9 to 10 inches of water pressure will meet most on-farm drying system needs. 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 are needed (Fig. 8-3).

These criteria dictate that bins should not initially be filled too full if the grain is at high moisture content. Once grain moisture reaches 15 percent or less throughout the bin, the bin filling process may be completed.

Dry grain (moisture content less than 15 percent) should not be mixed with moist grain (moisture content greater than 18 percent). Once a rice kernel is dried to a level below 15 percent, any rewetting may cause excessive fissuring and reduction in head rice yield. This also may occur if damp air is pumped through already-dry grain.

Stirring devices help to mix the upper and lower portions of grain in the bin. This speeds up the drying process and loosens the grain so that additional air may be moved up through the grain. Stir-alls

Fig. 8-4. Temperature is critical in drying rice.

and similar devices should not be turned on unless the bottom end of the auger is about 1 foot deep in grain. They can run almost continuously after that point, when the drying fans are running. Many producers are concerned that these devices may grind away at the rice if left on, but there is no research evidence to support this claim. A small amount of flour-like substance will form around the auger top, but the small particles were most likely already there and are just being gathered in one place with the auger action.

Grain should not be allowed to cone as the bin is being filled. If coning occurs, the large particles will migrate to the outside and the flour-like small particles and trash will remain at the center of the cone. This results in a very uneven airflow through each portion of the grain bin. Most of the air will pass up the outside of the bin through the larger and cleaner grain. A level height should be maintained through the filling process. Once particle separation occurs, it is hard to correct even if the bin is later shoveled level.

Air temperature is important when drying rice. When air is being pushed through deep depths for prolonged periods of time, the air temperature should not exceed 105 degrees F (Fig. 8-4). If higher temperatures are used, the rice kernel can be overheated, resulting in low milling characteristics. Commercial dryers can use much higher air temperatures than on-farm dryers because the rice is subjected to heated air for shorter periods of time. Rice can be successfully dried on the farm, but different management techniques are necessary than when drying commercially.

Some of the main causes of problems that occur with on-farm drying are:

1. Hurrying the drying process to make room for freshly harvested rice.

2.Using drying temperatures that are too high, resulting in extremely low humidity drying air causing over-dried and stress-cracked rice and low head rice yields.

3. Attempting to dry with insufficient airflow, usually caused by excessive depth of high moisture rice.

4. Lack of attention after rice has been dried to at least 13 percent.

5. Harvesting rice with a moisture content in excess of 20 percent to be dried in on-farm facilities.

6. Inadvertently rewetting dried rice by aerating with high humidity air. Usually occurs if fans are run night and day with no addition of heat at night.

Suggested Steps for On-farm Rice Drying

1. Harvest rice at 20 percent or less and avoid attempting to dry rice on the farm if the moisture at harvest exceeds 20 percent.

2. Clean the rice to be dried as much as practical by adjusting harvesting equipment to minimize the amount of foreign material.

3. Determine the rice moisture content of incoming rice and avoid mixing rice of different moisture contents once its moisture content has reached 15 percent or less.

4. Place the rice harvested first in the drying bin at a depth of 6 to 12 feet. When layer drying, this depth is dependent on the initial moisture content of the rice and the capabilities of the fan.

5. Level the rice equally across the entire drying bin at the depth selected. It is very important to level the rice in order to equalize the pressure throughout all horizontal cross-sections of the bin to obtain uniform airflow.

6. Open air exits so that air can exhaust readily from the drying bin.

7. Turn on the fans as soon as the ducts or the perforated floor is covered with approximately 1 foot or more of rice.

8. If possible, do not hold wet rice in a bin, truck, combine hopper or grain cart longer than 12 hours without moving air through the container to cool the rice.

9. Measure the relative humidity and temperature of the ambient air to determine the maximum temperature setting of the heater.

10. Exercise extreme caution when rice kernel temperature exceeds 100 degrees F.

11. Dry high moisture rice in shallow batches until the rice moisture content is 15 percent or less. Then, deeper depths with lower airflow requirements are acceptable.

12. Drying time per batch is dictated by air flow rate, measured as cubic feet per minute (CFM) per hundredweight (cwt), temperature difference between air entering and leaving the rice, the moisture content of the ambient air, and the original moisture content of the rice.

13. The best way to reduce drying time is to increase airflow.

14. Once the rice has reached 15 percent moisture, move it to another bin where the depth can be increased and the airflow per cwt can be decreased. Continue drying by controlling relative humidity of the drying air.

15. Once the rice is 12.5 to 13 percent grain moisture through the entire depth of storage, fill the storage bin and level the grain surface.

16. Aerate to cool the grain kernels for the next few weeks when the humidity is below 60 percent and the air is cool (50 to 60 degrees F).

17. Do not operate fans when ambient temperature is below 32 degrees F.

18. Probe the bin periodically (once a week is ideal) for temperature or moisture variation.

19. Normally, the first place that moisture migration will occur is the center of the top layer. If there is any indication that moisture or temperature is increasing in this area or other areas, turn on the fans to cool and/or dry moistened rice.

20. Do not let any spoiled rice mix with good rice.

21. Periodic aeration may be necessary to counter extreme temperature changes during storage.

Chapter 9

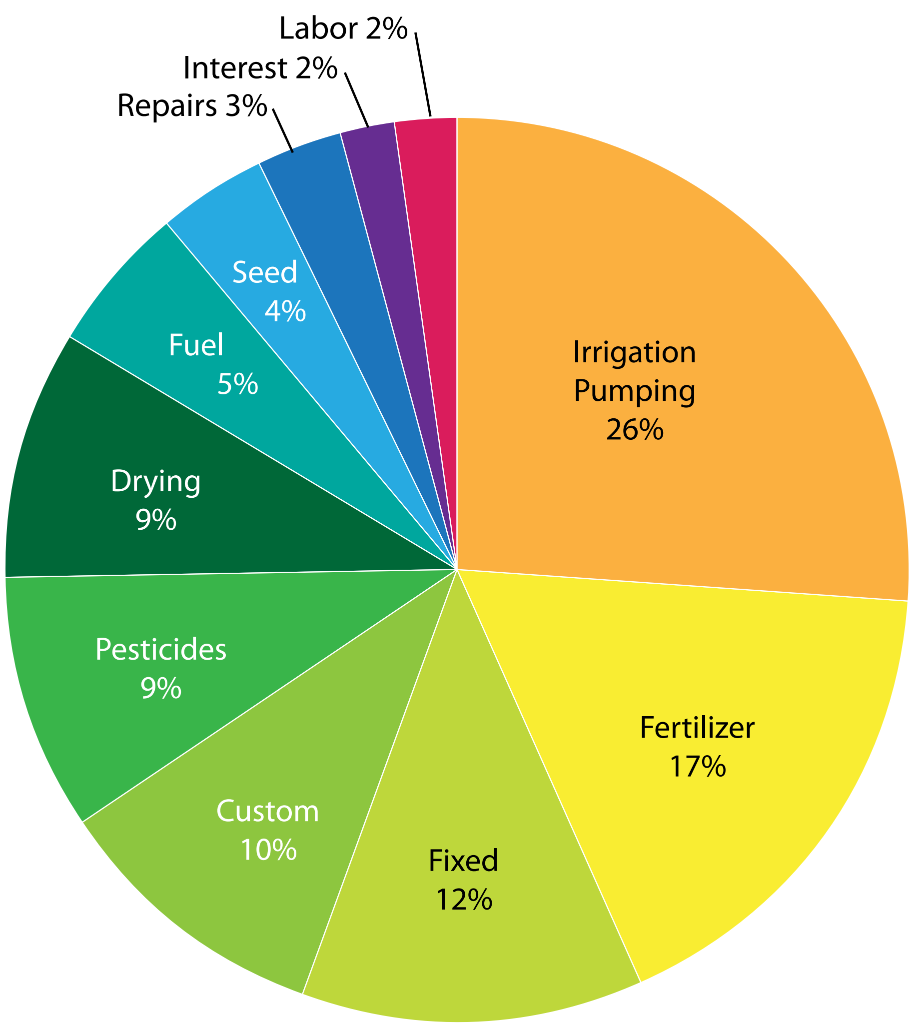
Rice Production Economics

Michael Salassi

Production Costs

Rice is produced in Louisiana under several different types of agronomic production systems. It may be water-seeded by airplane onto a flooded field or drill-seeded by tractor and grain drill on a dry field. It may be produced in a crop rotation, following soybeans, crawfish or some other commodity, or it may be produced following a fallow year. Tillage options include conventional tillage or stale seedbed. Rice variety produced may be conventional, herbicide-resistant or hybrid. Source of irrigation water may be from a deep well groundwater source or a surface canal source. All of these production system options have a direct impact on rice production costs.

The figure below provides a general percentage breakdown of the major production cost items associated with rice production in Louisiana. Irrigation pumping cost (26%), fertilization cost (17%), fixed equipment costs (12%) and custom charges (10%) comprise the major cost items associated with rice production in Southwest Louisiana. Irrigation pumping costs are generally lower for surface water



sources in Southwest Louisiana and for both water sources in Northeast Louisiana. Total variable production costs for rice in Louisiana are in the range of $650 to $750 per planted acre. Total fixed equipment production costs are the range of $80 to $100 per acre. In Southwest Louisiana, a portion of the rice acreage is ratoon cropped each year. This second production period following the first crop harvest generally entails application of nitrogen, reflooding the field for a period of time, then draining the field just prior to harvest.

Most of the rice acreage in production in Louisiana is produced on leased land. Share rental arrangements are the most prevalent type of crop lease arrangement being utilized. Under these types of rental arrangements, the producer and the landlord each pay a specified portion of the production expenses. One survey of rice producers in the state indicated that the two most common types of rice share rental arrangements were: (1) an 80/20 arrangement where the grower received 80% of the crop market and government program income and paid all variable production expenses, including irrigation pumping cost, with the exception of 20% of drying expenses paid by the landlord who received 20% of the crop market and government program income and (2) a 60/40 arrangement where the grower received 60% of the crop market and government program income and paid all variable production expenses, excluding irrigation pumping cost and 40% of fertilization, pesticide and drying expenses paid by the landlord who received 40% of the crop market and government program income. Although these two share arrangements are most common, they do not represent the majority of rice share arrangements, as grower-landlord share arrangements for rice can vary greatly. Some rice tracts are leased under a cash rental arrangement. In these cases, the producer generally pays all production expenses and receives 100% of the crop market and government program income. Average rice cash rental rates, based upon the same survey data, and were in the range of $75 to $100 per planted acre.

Marketing

Over the past five years, slightly more than half of the rice produced in the United States (54%) is marketed domestically, with the remainder (46%) being exported to foreign countries. The domestic rice market has more than doubled over the past 25 years. Approximately 97% of domestic rice use is for food use, both directly and in processed foods, and industrial uses. Direct food use of rice accounts for more than half of total use, Use of rice in processed foods (package mixes, cereal and rice cakes) accounts for about 18% of total use. The remaining domestic use of rice is used in pet foods and in beer production.

About 70% of rice exported in milled form and the remaining 30% exported as rough rice. Latin America is the primary export market for U.S. rice, representing about one half of total U.S. rice exports. Specific countries which have are top U.S. rice export markets include Mexico, Japan, South Korea, Iraq, Saudi Arabia, Haiti, Canada, Nicaragua, Costa Rica, Honduras and Venezuela. Because such a large portion of U.S. rice production is exported, the global rice market has a significant impact on U.S. domestic price levels. The United States is essentially a price-taker in the world rice market, with Thailand and Vietnam driving world market forces.

Futures contracts for U.S. rough rice are traded on the Chicago Board of Trade (CBOT). The main functions of a futures market are price risk management and price discovery. Price risk can be managed by hedging rough rice contracts on the exchange. Price risk management relates to alternative commodity selling or market strategies, including hedging in the futures market, to reduce exposure to market price volatility. Price discovery is the generation of information about "future" cash market prices through futures markets using basic supply and demand factors.

Hedging provides an opportunity to lock in a rough rice price, as gains or losses in the cash market are usually offset by positions held in the futures market. Use of the futures market to manage price risk is available to rice producers, mills, merchandisers, food processors, exporters and importers. The futures market also provides a means of price discovery for the rice industry. Daily quotes of rough rice prices for future delivery serve as predictions of what buyers and sellers in the rice market expect prices to be at that time. The term "basis" refers to the difference between the local cash price of the commodity and the futures price. The basis can be positive or negative and is influenced by transportation costs and other factors. Contract specifications for the rough rice futures contracts traded on the Chicago Board of Trade are shown in Appendix Tables 3, 4, and 5.

Glossary

Active ingredient (ai) — Component of a pesticide that has toxic activity against the pest in contrast to the inert or inactive ingredients.

Abiotic — Literally "without life," refers to problems not caused by pathogens.

Adventitious — Refers to a structure arising from an unusual part, such as roots growing from stems or leaves.

Amylographic — Spectrographic analysis of starch.

Amylose — Type of starch in rice grain; higher content makes rice cook drier.

Amylopectin — A polymer of glucose associated with the outer layers of starch grains; higher content makes rice cook stickier.

Anaerobic — Literally "without air," refers to an organism able to live and grow without air or oxygen.

Antagonistic — Decreased activity of an organism or chemical from the effect of another organism or chemical.

Apical meristem — Rapidly dividing cells at the tip of plant organs such as roots and stems; the growing point.

Ascospores — The sexual spores of one group of fungi.

Auricle — An ear-shaped structure at the junction of the leaf blade and leaf sheath of grasses such as rice.

Axillary bud — A bud located between the leaf sheath and stem where the leaf sheath attaches to the stem.

Bacterium (pl. bacteria) — A one-celled microscopic organism that lacks chlorophyll and multiplies by fission (splitting apart).

Biological control — Disease control by means of predators, parasites, competitive microorganisms and decomposing plant material that restrict or reduce the population of the pathogen.

Biotype — Genetic variant of a species.

Boot — Growth stage of rice when the panicle is more than 1 inch long but before emergence (heading).

Brewers — Smallest size kernels of broken milled rice that is less than one-quarter of the whole kernel.

Broken yield Pounds of broken grain milled from 100 pounds of rough rice (total milling yield — head milling yield).

Brokens — Milled rice kernels that are smaller than three-fourths of the whole kernel. This includes second heads, screening and brewers.

Brown rice — Rice kernels with only the hulls removed.

Carbohydrate — A class of organic chemicals composed of carbon, hydrogen and oxygen; in plants, photosynthesis-produced sugars and starch are examples.

Chevrons — Stripe-like pattern consisting of several curved or V-shaped bands.

Chlorophyll — Green pigment associated with photosynthesis.

Chlorosis — Yellowing of normally green tissue caused by the destruction of chlorophyll or the partial failure of chlorophyll to form.

Coalesce — The coming together of two or more lesions to form a large spot or blotch.

Coleoptile — The protective covering of an emerging shoot; it is not the true leaf.

Commingled rice — Rice that has been blended with other rice of similar grain type, quality and grade.

Conidiophore — Specialized hypha-bearing asexual spores called conidia.

Conidium (pl. conidia) — A spore formed asexually, usually at the top or side of a specialized hypha (conidiophores).

Crown — Junction between stem and root.

Culm — The jointed stem of grass.

Damage — Economic loss to a crop caused by an insect, disease or injury.

Dead heart Condition where the growing point (apical meristem) of the stem dies.

Debris — The crop residues left from the previous crop.

Denitrification — Conversion of nitrate nitrogen to gaseous nitrogen.

Dough — The stage when the endosperm of the grain has begun to solidify.

Drift — The spread of airborne spray droplets to nontarget areas.

Drying — Removal of kernel moisture to obtain a safe storage condition (12.5 percent moisture).

Eclosing — Emergence of an insect from its egg or a pupal case; hatching.

Economic injury level — The lowest pest density that will cause damage equal to the cost of control.

Economic threshold — The density of a pest at which control action must be taken to prevent a pest from reaching the economic injury level.

Embryo — The microscopically small plant at the base of a rice kernel. The germ.

Endemic — The normal presence of a pest in a crop year after year in less than epidemic amounts.

Endosperm — The stored food of a seed outside of the embryo composed mostly of starch in rice.

Enzyme — Protein specialized to catalyze chemical reactions related to metabolic activity necessary for growth.

EPA — Environmental Protection Agency, an agency of the U.S. government.

Epidermis — The outer layer of cells on all plant parts.

Epiphytotic or epidemic — The extensive development of a disease in a geographical area.

Etiology — The study of the causes of disease.

Fissuring — The cracking or breaking of grains prior to harvest caused by alternating periods of wetting and drying.

Flag leaf — The uppermost leaf of the rice plant, immediately below the panicle.

Floret — The rice flower including lemma, palea and reproductive floral parts.

Flush — Flooding of the field with drainage soon after for the purpose of keeping the seedbed moist.

Foliar — Of or referring to the leaves of a plant.

Fungus (pl. fungi) — An undifferentiated plant lacking chlorophyll and conductive tissues.

Gelatinization temperature — Index to classify the cooking types of long, medium and short grains.

Gibberellic acid (GA) — Plant growth hormone that stimulates elongation.

Glume — A tiny modified leaf at the base of the rice kernel.

GMO — Genetically modified organism; usually refers to an organism into which a gene or genes not naturally found in that organism has been inserted.

Green rice — Rough rice from which the excess moisture has not been removed (usually 18.5 to 22.5 percent moisture).

Green ring — Rice plant growth stage during which the tissue of the first internode appears green because of the accumulation of chlorophyll, indicates a change from vegetative to reproductive growth and the beginning of internode elongation.

GPA — Gallons per acre.

Heading — The period during which panicles exert from the flag leaf sheath.

Head rice — Milled rice kernels that are more than three-fourths of the whole kernel.

Head row — A short row of plants grown from the seed of a single panicle or head of rice.

Head milling yield — Pounds of head rice milled from 100 pounds of rough rice.

Horizontal resistance — A uniform resistance against all races of a pathogen. The level of resistance is usually only moderate and often influenced by the environment.

Hulling — A process of removing husks from rough rice.

Hulls — Outer husk of the rice grain, usually a waste product but can be used in rice mill feed and as a filler for feed products. Actually the lemma and palea of the floret.

Hybrid rice — Rice produced from a single cross between two different lines. An F1 hybrid.

Hydrophopic — Resistant to wetting.

Hypha (pl. hyphae) — A single thread or filament of a fungus.

Imbibe — Absorption of water.

Infestation level — Percent of the population affected by a pathogen, or density of pest in a unit area.

Inflorescence — A flower cluster. In rice, it is a panicle.

Injury — Feeding by an insect on a crop but not necessarily causing economic loss.

Instant rice — Milled rice that is cooked, cooled and dried under controlled conditions and packaged in a dehydrated form. Before packaging, it is enriched with thiamine, riboflavin, niacin and iron.

Instar — The stage of an insect between molts.

Internode — The tissue of a rice stem between two nodes (joints).

Internode elongation — Jointing, the rapid lengthening of the tissue between nodes of a rice stem. Begins with accumulation of chlorophyll in the stage called green ring.

IPM — Integrated pest management; the reduction of plant pests through the combined use of various control practices.

Joint — The section of a stem defined by two nodes and the internode.

Key pest — A pest that causes economic loss in most years.

Label — Document accompanying a pesticide container giving specific information about a pesticide, also a legal document specifying how and when a product can be used.

Larva — The second developmental stage of insects with complete metamorphosis (egg, larva, pupa, adult). Larvae look different from adults, live in different places and feed on different food.

Lemma — The larger of two enclosing structures that form the hard outer covering (hull or husk) of a rice seed.

Lesion — A localized area of diseased tissue of a host plant.

Ligule — Structure found at the junction of the leaf blade and leaf sheath of a grass plant where the blade contacts the stem.

Lodging — The leaning or falling over of rice plants before harvest.

Long-grain rice — Rice that is long and slender, measuring 1/4 inch or more in length. Kernel size is 6.5 mm or more long, and the length-width ratio is from 3.27 to 3.41:1.

Main shoot — The first noticeable aboveground portion of a rice plant originating directly from the seed.

Medium-grain rice — Rice that is plump, measuring less than 1/4 inch long. Kernel size is from 5.37 to 6.06 mm or has a length-width ratio of from 2.09 to 2.49:1.

Meristem — Region of rapidly dividing cells.

Mesocotyl — Portion of the shoot between the seed and the cotyledon.

Metamorphosis — A change in form during development.

Milk — The stage when the endosperm of the grain is the consistency of milk.

Milled rice — Rice grain from which husks, bran and germ have been removed.

Milling — Processing the rough rice into milled or brown rice.

Mycelium (pl. mycelia) — A mass of fungus hyphae; the vegetative body of a fungus.

Neck — Region of the head consisting of the joint below the panicle.

Necrotic — Dead.

Nematode — Generally microscopic, unsegmented roundworm, usually threadlike, free-living or a parasite of plants or animals.

Node — The pronounced area of rice stem from which a leaf originates.

Nymph — The immature stage of insect with incomplete metamorphosis (egg, nymph, adult). Nymphs look similar to adults, live in the same place as adults and feed on the same food.

Occasional pest — A pest that sometimes causes economic loss.

Overwinter — A term used to describe a pest's ability to survive the winter. The overwintering stage and site are important.

Oviposition — The act of an insect laying an egg or eggs.

Palea — The smaller of two enclosing structures that form the hard outer covering of a rice seed.

Panicle — A type of inflorescence consisting of a main axis with branches arranged on it.

Panicle 2mm — Same as panicle differentiation.

Panicle differentiation (PD) — Rice plant growth stage during which the panicle is recognizable as a small tuft of fuzz about 2 mm (1/8 inch) long.

Panicle initiation (PI) — Rice plant growth stage during which a specialized group of cells in the growing point begin to actively divide. It often corresponds to or closely follows green ring and can be positively identified only with magnification.

Parboiled rice — Rough rice soaked in warm water under pressure, steamed and dried before milling.

Parboiling — A process by which rough rice is steeped in water, steamed or heated to gelatinize starch, then subsequently dried.

Pathogen — A specific agent that causes infectious disease.

Pathogenic — Capable of causing disease.

Pedicel — The stem or stalk supporting the individual florets (grains) in the inflorescence.

Penultimate — The next to last syllable in a word.

Perithecium (Pl. perithecia.) — A flask or globe shaped sexual spore bearing structure with an opening at one end characteristic of certain fungi.

Pest — Any destructive organism that competes with humans.

pH — A measure of the acidity or alkalinity of soil, water or solutions. Values range from 0 to 14 with 7 being neutral, less than 7 acidic and above 7 alkaline.

Photosynthesis — The process by which plants absorb light and in the presence of chlorophyll convert carbon dioxide and water to glucose and oxygen.

Physiological — Of or relating to processes in cells, tissues and organs associated with growth and development of an organism.

Phytotoxic — Having the ability to cause injury to a plant.

Pollination — Transfer of pollen from the male to female flower structures.

Precooked rice — Milled rice that has been processed by various methods to make it cook quickly.

Processed rice — Rice used in breakfast cereals, soups, baby foods and packaged mixes.

Pupa — The third stage of insects with complete metamorphosis (egg, larva, pupa, adult). A pupa does not feed, but is in a resting stage.

Pycnidium (Pl. pycnidia) — A spherical or flask shaped asexual spore-producing structure characteristic of some fungi.

Radicle — First root of a germinating seed.

Ratoon crop (second crop) — Production of harvestable rice from regrowth of rice from the stalks harvested earlier.

Resistance — The inherent ability of a host plant to suppress, retard or prevent entry or subsequent activity of a pathogen or other injurious factor.

Rice bran — Tissue directly beneath the hull containing the outer layers of the seed coat and parts of the germ. Bran is rich in protein and vitamin B. It is used as livestock feed and vitamin concentrates. It is part of the fiber of whole grains.

Rice polish — A layer removed in the final stages of milling that is composed of the inner layers of the seed coat. It is rich in protein and has high fat content; used in livestock feed and baby food.

Rough rice (paddy) — Rice grains with the hulls, but without any part of stalk; consists of 50 percent or more of paddy kernels (whole or broken unhulled kernels of rice).

Saprophytic — Referring to an organism that derives its nutrition from dead or decaying organic matter.

Saturated soil — *C*ondition when all soil pore spaces are full of water.

Sclerotium (pl. sclerotia) — Dense, compacted mass of hyphae, resistant to unfavorable conditions and can remain dormant for long periods; able to germinate when favorable conditions return.

Screenings — Broken milled rice that is more than one-half of the whole kernel size.

Second heads — Largest size of broken milled rice that is more than one-half of the whole kernel size.

Semidwarfs — Plants changed genetically to a reduced plant height.

Scenescence — The process of aging leading to death after the completion of growth in plants and individual plant parts.

Shoot — New growth originating from a crown in rice.

Short-grain rice — Rice that is almost round. Kernel size ranges from 4.56 to 5.01 mm in length, and the length-width ratio varies from 1.66 to 1.77:1.

Skipper — A group of insects closely related to moths and butterflies. Adult skippers have knobs on the end of antennae (similar to butterflies), and the antennae are widely spaced on the head (similar to moths).

Sorus (Pl. sori) — A compact group of spores or spore-bearing structures associated with certain fungi.

Spikelet — In rice, a single floret, below which are two reduced bracts. Each bears a single grain.

Spore — A minute propagative unit that functions as a seed but differs from it in that a spore does not contain a preformed embryo. The fruit of certain fungi.

Spreader variety — A variety very susceptible to a given disease that is planted among test varieties or lines to serve as a source of disease inoculum.

Stale seedbed — Seedbed prepared several weeks or months prior to planting. A component of reduced tillage management.

Stooling — Tillering.

Stubble — Rice stalks and their associated crowns remaining after harvesting.

Straighthead — Physiological disorder characterized by sterile, deformed seeds and upright panicles.

Sun checking — Fissuring.

Susceptibility — The inability of a plant to resist the effect of a pathogen or other damaging factor.

Suppression — The act of reducing or holding back rather than eliminating.

Tiger moth — A group of moths with hairy caterpillars (the woolly bear).

Tiller — A young vegetative shoot arising from nodes at the base of the plant; most can produce a panicle.

Tillering — The period during which tillers are formed, usually beginning at the 4- to 5-leaf stage and continuing until early reproductive growth. Also the process of forming tillers.

Tolerance — Amount of pesticide that can safely remain in or on raw farm products at time of sale, or the ability of a plant to yield equally under diseased condition as healthy.

Total milling yield — Pounds of head, brewers, second heads and screenings milled from 100 pounds of rough rice.

White rice — Total milled rice after the hulls, bran layer and germ are removed. This includes head rice and broken rice.

Y-leaf — The most recently expanded leaf, at least three-fourths unfurled. The leaf is usually selected for tissue analysis.

Appendix

Table 1. Principle Rice Varieties Released from the LSU AgCenter Rice Research Station.

Variety	Grain Type	Year Released	Breeders Involved
Colusa	Short	1917	Chambliss, Jenkins
Fortuna	Long	1918	Chambliss, Jenkins
Acadia	Short	1918	Chambliss, Jenkins
Delitus	Long (A)*	1918	Chambliss, Jenkins
Tokalon	Long	1918	Chambliss, Jenkins
Evangeline	Long	1918	Chambliss, Jenkins
Rexora	Long	1928	Chambliss, Jenkins
Nira	Long	1932	Chambliss, Jenkins
Magnolia	Medium	1945	Jodon
Lacrosse	Medium	1949	Jodon
Sunbonnet	Long	1953	Jodon
Toro	Long	1955	Jodon
Nato	Medium	1956	Jodon
Saturn	Medium	1964	Jodon
Della	Long (A)	1973	Jodon
Vista	Medium	1973	Jodon, McIlrath
LA 110	Medium	1979	McIlrath, Jodon
Leah	Long	1982	Trahan, Jodon
Toro-2	Long	1984	McKenzie, Jodon
Mercury	Medium	1987	McKenzie
Lacassine	Long	1991	Linscombe, Jodari
Bengal	Medium	1992	Linscombe, Jodari
Cypress	Long	1992	Linscombe, Jodari
Jodon	Long	1994	Linscombe, Jodari
Dellrose	Long (A)	1995	Jodari, Linscombe
Lafitte	Medium	1996	Linscombe, Jodari
Cocodrie	Long	1998	Linscombe
Dellmati	Long (A)	1999	Jodari, Linscombe
Earl	Medium	2000	Linscombe
CL 121	Long	2001	Linscombe, Sha
CL 141	Long	2001	Linscombe, Sha
CL 161	Long	2002	Linscombe, Sha
Cheniere	Long	2003	Linscombe, Sha
Pirogue	Short	2003	Linscombe, Sha

Table 1 continued on next page

* (A)-aromatic

Table 1. continued from page 139

Variety	Grain Type	Year Released	Breeders Involved
Ecrevisse	Short	2004	Linscombe, Sha
CL 131	Long	2005	Linscombe, Sha
Jupiter	Medium	2005	Sha, Linscombe
Trenasse	Long	2005	Linscombe, Sha
CL151	Long	2008	Linscombe, Sha, Blanche
Catahoula	Long	2008	Linscombe, Sha, Blanche
Neptune	Medium	2008	Sha, Linscombe, Blanche
Jazzman	Long (A)	2009	Sha, Linscombe, Blanche
CL111	Long	2010	Linscombe, Sha
CL261	Medium	2010	Linscombe, Sha
Caffey	Medium	2011	Linscombe, Blanche, Sha
CL152	Long	2011	Linscombe, Sha
Jazzman-2	Long (A)	2011	Sha, Linscombe
Della-2	Long (A)	2012	Sha, Linscombe
Mermentau	Long	2012	Linscombe, Sha

* (A)-aromatic

Table 2. Sequence of Events in the Development of the Rice Variety Catahoula-Pedigree 9502008-A/Drew.

STEP	YEAR	GENERATION	ID	STAGE OF DEVELOPMENT
1	1997	F_0	97CR346	Artificial Hybridization
2	1998	F_1	98T027	F_1–Space Plant Nursery
3	1999	F_2	99F7041-7042	F_2–Bulk–Segregation
4	2000	F_3	0028270	F_3–Headrow–Segregation
5	2001	F_4	0116926	F_4–Headrow–Segregation
6	2002	F_5	0202519	F_5–PY Test–Purification
7	2003	F_6	0302082	F_6–URN & CA–Purification
8	2004	F_7	0302082	F_7–URN & CA–Purification
9	2005	F_8	0302082	F_8–URN & CA–Purification
10	2006	F_9	0302082	F_9–URN & CA–Purification
11	2006	F_{10}	0302082	Headrow Increase–Puerto Rico
12	2007	F_{11}	0302082	Foundation Seed Field–RRS
13	2008	F_{12}	Catahoula	Registered Seed Production

Table 3. Rough Rice Futures Contract Specification - CME Group

<table>
<tr><td>Contract Size</td><td>2,000 hundredweight (cwt.)
(~ 91 metric tons)</td><td>Contract Months</td><td>January, March, May, July, September, November</td></tr>
<tr><td rowspan="4">Deliverable Grades</td><td rowspan="4">U.S. No. 2 or better long grain rough rice with a total milling yield of not less than 65% including head rice of not less than 48%. Premiums and discounts are provided for each percent of head rice over or below 55%, and for each percent of broken rice over or below 15%. No heat-damaged kernels are permitted in a 500-gram sample and no stained kernels are permitted in a 500-gram sample. A maximum of 75 lightly discolored kernels are permitted in a 500-gram sample.</td><td>Last Trading Day</td><td>Business day prior to the 15th calendar day of the delivery month .</td></tr>
<tr><td>Last Delivery Day</td><td>Seventh business day following the last trading day of the month.</td></tr>
<tr><td>Trading Hours</td><td>Open Auction (trading floor): 9:30 a.m. - 2:00 p.m. Central Time, Monday-Friday
CME Globex (electronic): 5:00 p.m. - 2:00 p.m. Central Time, Sunday-Friday
Trading in expiring contracts closes at noon on the last trading day.</td></tr>
<tr><td>Ticker Symbols</td><td>Open Auction: RR
Electronic: ZR</td></tr>
<tr><td>Tick Size (minimum fluctuation)</td><td>1/2 cent/hundredweight ($10/contract)</td><td rowspan="2">Daily Price Limit</td><td rowspan="2">Fifty cents ($0.50) per hundredweight expandable to $0.75 and then to $1.15 when the market closes at limit bid or limit offer. There shall be no price limits on the current month contract on or after the second business day preceding the first day of the delivery month.</td></tr>
<tr><td>Pricing Unit</td><td>Cents/hundredweight</td></tr>
<tr><td colspan="4">Source: CME Group.</td></tr>
</table>

Table 4. Grades and grade requirements for the classes of long grain, medium grain, short grain and mixed milled rice

Grade	Maximum limits of:											Color requirement	Milling requirement
	Seeds, heat-damaged, and paddy kernels (single or combined)		Red rice and damaged kernels	Chalky kernels		Broken kernels				Other types			
	Total (number in 500 grams)	Heat-damaged kernels and objection-able seeds (number in 500 grams)	(singly or combined percent)	In long grain rice (percent)	In medium or short grain rice (percent)	Total (percent)	Removed by a 5 plate (percent)	Removed by a 6 plate (percent)	Through a 6 sieve (percent)	Whole kernels (percent)	Whole and broken kernels (percent)	(minimum)	(minimum)
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:
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.

Source: United States Standards for Rice, Federal Grain Inspection Service , U.S. Department of Agriculture.

Table 5. Grades and Grade Requirements for the Classes of Long-Grain, Medium-Grain, Short-Grain and Mixed Milled-Rice

Grade	Maximum limits of: Seeds, heat-damaged, and paddy kernels (single or combined): Total (number in 500 grams)	Seeds, heat-damaged, and paddy kernels: Heat-damaged kernels and objectionable seeds (number in 500 grams)	Red rice and damaged kernels (singly or combined %)	Chalky kernels: In long-grain rice (%)	Chalky kernels: In medium- or short-grain rice (%)	Broken kernels: Total (%)	Broken kernels: Removed by a 5 plate (%)	Broken kernels: Removed by a 6 plate (%)	Broken kernels: Through a 6 sieve (%)	Other types: Whole kernels (%)	Other types: Whole and broken kernels (%)	Color requirement (minimum)	Milling requirement (minimum)
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:
U.S. Sample grade shall be milled rice of any of these classes that: (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% of moisture; (c) is musty or sour, or heating; (d) has any commercially objectionable foreign odor; (e) contains more than 0.1% 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.

Source: *United States Standards for Milled Rice*, U.S. Department of Agriculture.

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ATTACHMENT 4

LOUISIANA CRAWFISH PRODUCTION MANUAL

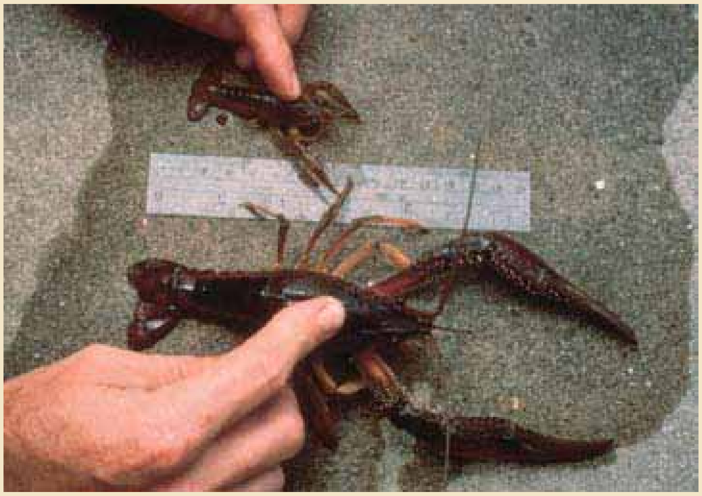

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Figure 1.1. Although they are outwardly similar at first glance, a number of characteristics distinguish the red swamp (left) and white river crawfish (right).

Whether from managed ponds or wild habitats, Louisiana's crawfish harvests are composed of two species – the red swamp crawfish (scientific name: *Procambarus clarkii*) and to a lesser extent the white river crawfish (scientific name: *Procambarus zonangulus*) (Figure 1.1). Although scientists in other parts of the world use the term "crayfish" for these and all related species, in this manual we refer to these two species as "crawfish" to reflect not just their common names, but also the widespread use of the word by producers, marketers and consumers in Louisiana and elsewhere in the United States.

Louisiana's crawfish farming industry has grown to include more than 1,200 farms occupying more than 120,000 acres. Production from wild habitats, mainly the Atchafalaya River basin, varies from year to year. Total production for the 2004-2005 season was more than 82 million pounds, with almost 74 million pounds from farms and more than 8 million pounds harvested from natural habitats by approximately 1,100 fishermen. The farm-gate and dockside value of the 2004-2005 harvest exceeded $45 million.

Crawfish ponds have no standard size, but most are between 10 and 40 acres, and most producers manage 150 or fewer acres (Figure 1.2). Occasionally, a single pond may include more than 1,000 acres, especially in bottomland areas where water levels are manipulated in natural habitats for crawfish production (Figure 1.3).

Formulated feeds are not used to produce crawfish. Instead, rice, sorghum-sudangrass or natural vegetation is grown in the summer (when ponds are drained) to serve as the base of a natural food chain for crawfish. Crawfish ponds are not stocked with hatchery-reared young as in other forms of aquaculture. Farmers rely on reproduction by unharvested crawfish from the previous year or on mature crawfish that are stocked to produce young naturally.

Figure 1.2. Although there is no "standard" crawfish pond, a successful pond must be built on flat land that will hold water and support a forage crop for the crawfish.

Figure 1.3. In some parts of Louisiana, semi-natural habitats are impounded to allow for crawfish production through control of natural hydrological cycles.

Educational and technical assistance in all aspects of crawfish production and marketing is provided by the LSU AgCenter through the Louisiana Cooperative Extension Service in every parish. Help is available through individual consultation, on-farm visits, production meetings and publications (Figure 1.4). Anyone considering going into crawfish farming should review current financial budgets available from the LSU AgCenter and discuss the feasibility of their projects or business plans with an extension professional who can identify the best available data for making decisions as to how to proceed. Louisiana Cooperative Extension Service agents and specialists are the best source of information on the feasibility of farming crawfish in your area.

History

Crawfish have been consumed for centuries by American Indians and in many parts of Europe. Commercial sales of crawfish in Louisiana began in the late 1800s. At that time, crawfish were harvested from natural waters throughout the southern region of the state. The first record of a commercial crawfish harvest in the United States was in 1880. That year, a harvest of 23,400 pounds was recorded, with a value of $2,140. By 1908, a U.S. Census

Profitability Varies

The profitability of crawfish farming changes from year to year because of the variable supply of wild and farm-raised crawfish, and resulting fluctuations in wholesale and retail prices. As a result of the unpredictable yields from pond to pond and year to year, few people make their living only from farming crawfish. Overall production on a crawfish farm depends greatly on whether the crawfish are grown in rotation with rice or in permanent crawfish ponds and on the size and management level of those ponds. Breakeven prices vary greatly from farm to farm and in different regions of the state.

Figure 1.4. Field faculty and state specialists with the LSU AgCenter are available to visit producers throughout the state.

report listed Louisiana's crawfish production at 88,000 pounds, with a value of $3,600.

In the years following the Great Depression, crawfish sold for as little as 4 cents per pound. During this period, with the development of improved transportation and cold storage, crawfish markets within Louisiana shifted from local consumption in rural areas to higher-volume markets in cities such as Baton Rouge and New Orleans. During this same period, the introduction of wire mesh crawfish traps provided fishermen a much more efficient method of harvest (Figure 1.5).

Figure 1.5. Even though the first crawfish traps were fairly simple designs, they enabled the industry to increase supply rapidly. Over the past two decades the construction and efficiency of commercial traps has improved tremendously.

In 1950, the Louisiana Legislature funded the Wildlife and Fisheries Commission to study the life history of crawfish in small ponds. By this time, the practice of re-flooding rice fields after grain harvest was occasionally practiced to produce crawfish for family consumption. This practice of crawfish "farming" eventually spread to closed-in woodlands and marshland as well.

Up until this time, most of the crawfish available for people to consume had come from wild harvests in natural habitats. Although crawfish were abundant some years because of high water levels in the Atchafalaya Basin and other natural wetland areas, in other years crawfish were scarce and difficult to come by. This variation in supply made it difficult for markets to grow, but once crawfish farming began, more consistent supplies were possible.

By the mid-1960s, the amount of land devoted to crawfish farming had increased to approximately 10,000 acres of managed ponds. At this point, an industry based on peeling crawfish became established, and the new markets for crawfish meat allowed both crawfish farming and wild harvests to increase even more (Figure 1.6). Acreage continued to increase in Louisiana, from approximately 44,000 acres in the mid-1970s to current levels of roughly 120,000 acres.

Small harvests of farmed crawfish for human consumption occur in other states, such as Texas, Arkansas, Mississippi, Alabama and the Carolinas, but Louisiana is by far the largest producer of crawfish in the United States. Official estimates are not available, but industry experts estimate that Louisiana usually accounts for 90 percent to 95 percent of the total U.S. production from year to year. The vast majority of crawfish aquaculture in the United States is focused on production for human consumption, but some pond-cultured crawfish are sold for fish bait or marketed as aquarium or scientific specimens.

How are Crawfish Classified?

Over the centuries, biologists have devised classification systems to represent groupings of animals and to better define where individual species fit within those groupings. With time, these systems have become more and more complicated, but this in turn provides more information about the relationships between species and groups of species. According to the most commonly accepted classification system, the red swamp crawfish and white river crawfish can be described as follows:

Kingdom: Animalia (animals)
Phylum: Arthropoda (crustaceans, insects, spiders, scorpions, etc.)
Subphylum: Crustacea (crustaceans)
Class: Malacostraca (crabs, pill bugs — rollie-pollies, krill, and related species and groups)
Order: Decapoda (meaning ten legs: lobsters, shrimp, crabs, crayfishes — also called crawfishes, and relatives)
Sub-Order: Pleocyemata
Superfamily: Astacoidea (all crayfishes)
Family: Cambaridae (cambarid crayfishes — one of three major groups of crayfish)
Subfamily: Cambarinae (a group of North American crayfish species, with more than 300 members)
Genus: *Procambarus*
Subgenus: *Scapulicambarus* (for red swamp crawfish), *Ortmanicus* (for white river crawfish)
Species: *clarkii* (for red swamp crawfish), *zonangulus* (for white river crawfish, which was previously called *acutus acutus* for many years)

Scientists often refer to animals and plants by their genus and species classifications. Thus, the red swamp crawfish is referred to as *Procambarus clarkii* and the white river crawfish is *Procambarus zonangulus*.

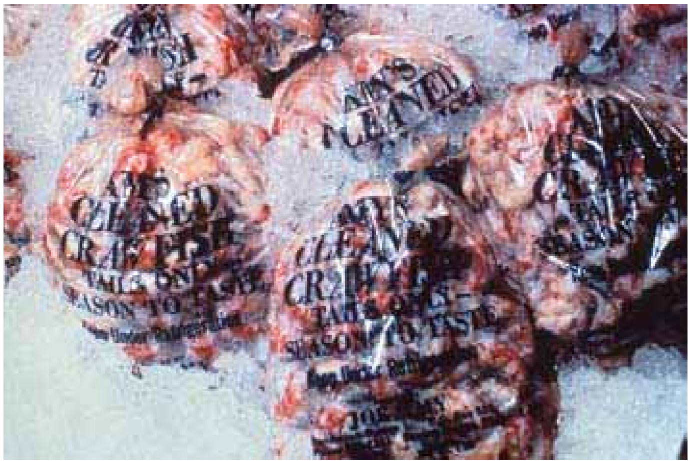


Figure 1.6. The earliest efforts at commercializing markets for crawfish tail meat involved simple methods, but allowed for marketing of fresh product to a wide consumer base.

As the crawfish farming industry began to expand during the 1950s and early 1960s, a number of people felt that for economic growth and benefits to take place, harvests would have to become even more predictable from year to year. Predictability, however, would require research to develop recommended production practices. In 1964, researchers in Louisiana State University's School of Forestry and Wildlife Management began conducting research on crawfish biology and improved methods for pond production.

Initial research focused on how best to manage crawfish ponds to provide a productive habitat, including what type of vegetation to plant, when to plant it, when to flood the ponds, how many crawfish to stock, how to discourage natural predators such as insects and wild fish and other basic topics (Figure 1.7). As time went on and the industry continued to grow, research focused on solving more problems, such as improving trap designs, developing formulated baits that would not have to be refrigerated or frozen, managing the amount and quality of water used in producing crawfish, evaluating the possibility for genetic improvement of crawfish, looking at new ways to process crawfish, developing new products made with crawfish meat and many other topics.

A large portion of Louisiana's crawfish aquaculture, in excess of 50 percent, is practiced in conjunction with rice production. Crawfish farming fits well into many existing farm operations by using marginal agricultural lands, crop rotations, and permanent farm labor and equipment during off-peak farming periods. Crawfish can be produced either in permanent rotation with a rice crop year after year in the same location or in a field rotation with rice and occasionally some other crop, with restocking of crawfish each rotational cycle. As the economics of rice production in Louisiana have weakened over recent decades, many rice producers have turned to crawfish as an accessory crop that can be integrated into their existing farming operations.

Additional Sources of Information

Additional information on crawfish aquaculture and the crawfish industry, including news articles, crawfish statistics, fact sheets and newsletters that do not appear in this production manual can be found on the LSU AgCenter's Web site. Several fact sheets on crawfish farming and other very informative fact sheets on aquaculture in the southern United States can be found on the Southern Regional Aquaculture Center's Web site. To locate this Web site, type in "Southern Regional Aquaculture Center Fact Sheets" in the search command of your favorite Internet search engine. Personnel in your local LSU AgCenter extension office can assist you in obtaining the most current information available on crawfish farming or other aspects of agricultural production associated with crawfish farming.

Natural Fishery

Historically, significant harvests of wild crawfish have occurred in Louisiana. This production moves through the same market channels as farmed crawfish, affecting prices received by farmers. In recent years, however, many of the traditional areas of wild harvest have failed to produce large volumes of crawfish. To what extent this reduction in wild harvest might reflect long-term trends in water management, climate and habitat alteration remains uncertain. Since 2000, less than 20 percent of Louisiana's harvests on average have come from the wild fishery.

Figure 1.7. Crawfish research has been conducted for many years by the LSU AgCenter in a number of administrative units, including the Aquaculture Research Station and the Rice Research Station.

Chapter 2. Crawfish Biology

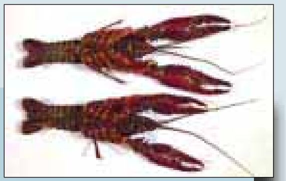
Procambarus clarkii (red swamp crawfish) and *P. zonangulus* (white river crawfish), the two species of commercial importance found in Louisiana crawfish ponds, have similar ecological requirements. As a result, it is not uncommon to find both species in the same pond. Both species are associated with natural cycles of flooding and drying common to much of Louisiana, and both construct burrows, in which they survive and reproduce during temporary dry periods. There are some differences between the two species, but care must be taken when reviewing information about the white river crawfish (see “How Are Crawfish Classified?” in chapter 1) because early references may refer to this species as *P. acutus acutus*, or *P. zonangulus*.

The red swamp crawfish produces more, but smaller, eggs than the white river crawfish, and it is capable of spawning year-round in the South. It appears to do better in more nutrient rich-waters than those of the white river crawfish. White river crawfish are seasonal spawners, usually spawning only in the autumn in the southern United States. Feeding rates have been found to be greater for the red swamp crawfish at temperatures in excess of 86 F, indicating a possible competitive advantage at higher temperatures. In contrast, the white river crawfish may grow faster at lower temperatures, and it typically reaches a slightly greater maximum size. Usually the red swamp crawfish are found in greater abundance in waters with lower dissolved oxygen (DO) content.

In general, both species are adapted to the conditions found in commercial crawfish ponds, and both respond well to the low input systems of production used in Louisiana. The abundance of one species or the other may vary among and within culture ponds over time, but the red swamp crawfish most often dominates and is the most desired species in the marketplace. White river crawfish are most often found in greatest numbers in ponds that are used to culture crawfish year after year.

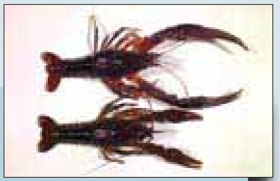
How these two species interact in crawfish ponds is not fully understood, but one hypothesis is that the red swamp crawfish tends to dominate in more ponds because of greater reproductive potential and a more prolonged reproductive season. No major difference in growth rate and survival between the two species has been observed under typical culture conditions. Some researchers suggest that later pond flooding dates (late October to November) may favor the white river crawfish because of its tendency to spawn later and its slightly larger hatchlings. These factors would provide an advantage over red swamp crawfish young that hatched at the same time. Recent research suggests that whichever species successfully produces large numbers of babies first during autumn months will predominate in the pond for the rest of the season. Much information is lacking, however, regarding interactions of these two species.

These two species are often similar in appearance, especially at a young age. They can be easily identified, however, by experienced persons. Despite efforts to exclude white river crawfish from many farms, both species will thrive under routine culture practices, and they often coexist in production ponds. No evidence exists of natural hybrids between these two species. Several books provide an excellent overview of the anatomy and biology of these and other crawfish species.



Red Swamp Crawfish

- *Procambarus clarkii*
- 70% – 80 % of annual catch in Louisiana
- Two halves of the carapace (head) meet to form a thin line
- Almost always have a blue-gray pigmented line on the underside of the tail
- Less elongated and more flattened claws than white river crawfish when mature
- Darker walking legs than white river crawfish
- Red pigment on adult bodies (except for rare color variations) – not always so with juveniles
- Lay eggs any time but mostly during fall and winter months
- Produce up to twice as many eggs as white river crawfish
- Thrive in systems flooded early in the fall
- Hatchlings smaller than white river crawfish
- Prefer swampy habitats
- Most young appear from September through December but can be found in all months
- Usually mature from April through June
- Native range is northeastern Mexico and the south central United States
- Commercially valued in Louisiana
- Introduced to many countries



White River Crawfish

- *Procambarus zonangulus*
- 20%-30% of annual catch in Louisiana
- Space called an “areola” separates each half of the carapace (head)
- No pigmented line on the underside of the tail as adult or juvenile
- More elongated and cylindrical claws than red swamp crawfish when mature
- Lighter walking legs than red swamp crawfish
- Never has red pigment on its body – sometimes adults can look pink
- Lay eggs only during mid- to late fall in Louisiana
- Produce fewer and larger eggs than red swamp crawfish
- Thrive in systems flooded in late fall
- Hatchlings larger than red swamp crawfish
- Prefer flooded wetlands with flowing, well-oxygenated water
- Usually mature from April through June
- All young appear from September through December in Louisiana
- Commercially valued in Louisiana
- Native range is Alabama, Louisiana, Mississippi and Texas
- Endemic only to the United States

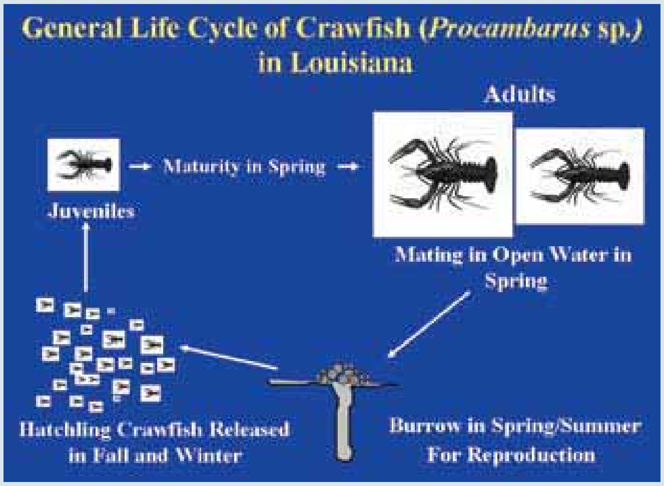


Figure 2.1. A diagram of the crawfish life cycle.

Life Cycles

Based on their distribution in North America, the red swamp and white river crawfish are classified as "temperate" species; that is, they will tolerate cold winter conditions. Both species, however, possess a number of traits that are usually associated with animals that live in warm waters. These species are short-lived (2 years or less), have high juvenile survival and can alternate between reproductively active and inactive forms. Moreover, *P. clarkii* is capable of spawning year-round in the southern United States, and some females can reproduce more than once per year.

These crawfishes have life cycles that are well-adapted to farm production strategies (Figure 2.1). Mature animals mate in open water where sperm is stored in a special receptacle, after which the female retreats to a burrow to eventually spawn. Burrowing activity can occur at any time but is most prevalent in late spring/early summer in Louisiana. Although spawning can take place in open water, the burrow provides protection while the fertilized eggs or young are attached to the underside of their mother's tail (Figure 2.2). Females carrying eggs or hatchlings are highly susceptible to predators, because they cannot use their normal tail-flipping escape response.

Figure 2.2. Crawfish eggs are typically laid and fertilized in the burrow where they become attached to the swimmerets on the underside of the female's tail.

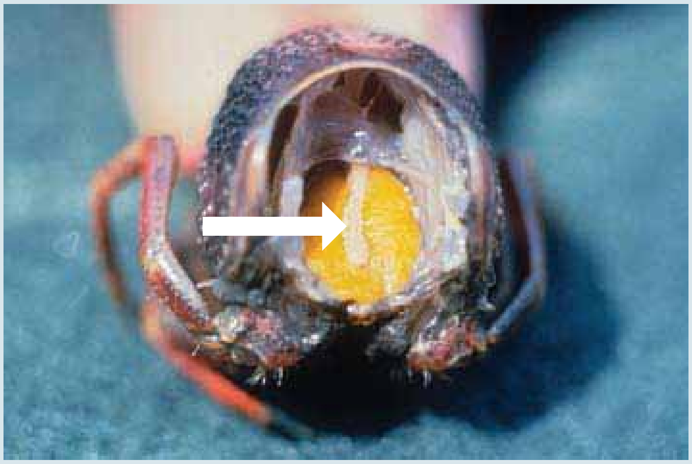
Figure 2.3. Crawfish burrows appear near the waterline in ponds when mature crawfish begin burrowing for reproduction. Burrows may or may not have the typical "chimney" associated with the entrance.

Crawfish of all ages and sizes, whether mature or immature and male or female, will dig or retreat to burrows to survive periods of dewatering. Crawfish ponds are usually drained during the summer months to allow for planting and growth of vegetation. Prior to draining, some mature crawfish burrow near the waterline (Figure 2.3). As the water level drops, additional crawfish burrows appear lower on the levee and are sometimes found on the pond bottom; however, the burrows on the pond floor often contain a high percentage of non-reproductive crawfish, such as males and immature juveniles.

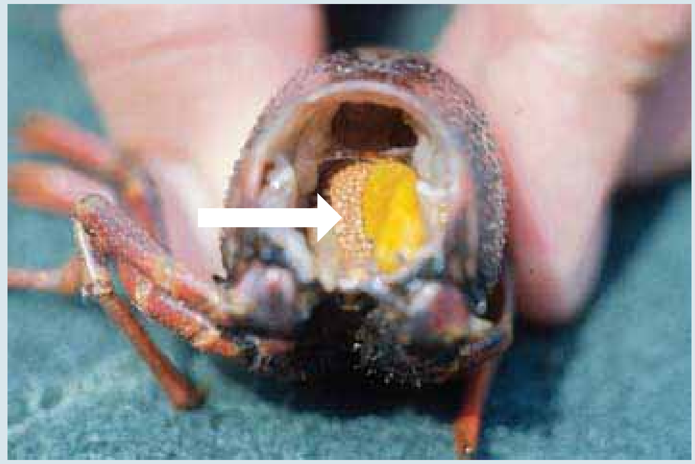
Ovarian (egg) development in mature females is temperature dependent, usually beginning prior to burrowing and reaching completion within the burrow. Developing eggs within the ovary become rounded, increase in size, and change from a light color to dark as they mature (Figure 2.4). At maturity, the large black eggs are shed from between the walking legs, are fertilized externally and are then attached to the swimmerets on the underside of the tail with an adhesive substance called glair. Although crawfish can survive in high humidity within the burrow, some standing water is necessary for successful reproduction. The number of eggs laid varies with female size and condition, but large red swamp or white river crawfish females can have more than 500 eggs.

The hatching period depends on temperature and usually takes about 3 weeks. Hatched crawfish are attached to the female's swimmerets through two molting phases, after which they resemble an adult crawfish and begin to feed. Hatchlings instinctively remain with the female for several weeks after their second molt although they are no longer attached. It is critical that the female and her young leave the burrow within a reasonable time because little food is available in burrows. When conditions force the crawfish to remain in the burrow, increased mortality can occur.

Pond flooding or heavy rainfall is usually necessary to encourage female crawfish to emerge from their burrows. Females emerge with their young (or sometimes with eggs) attached to their tails (Figure 2.5), and advanced hatchlings are quickly separated from their mother as she moves about in the open water. Because reproduction is somewhat synchronized in pond-reared crawfish, ponds are routinely flooded in autumn to coincide with the main period of reproduction. White river crawfish are autumn and winter spawners, but red swamp crawfish reproduction may occur at any time. Peak reproduction of



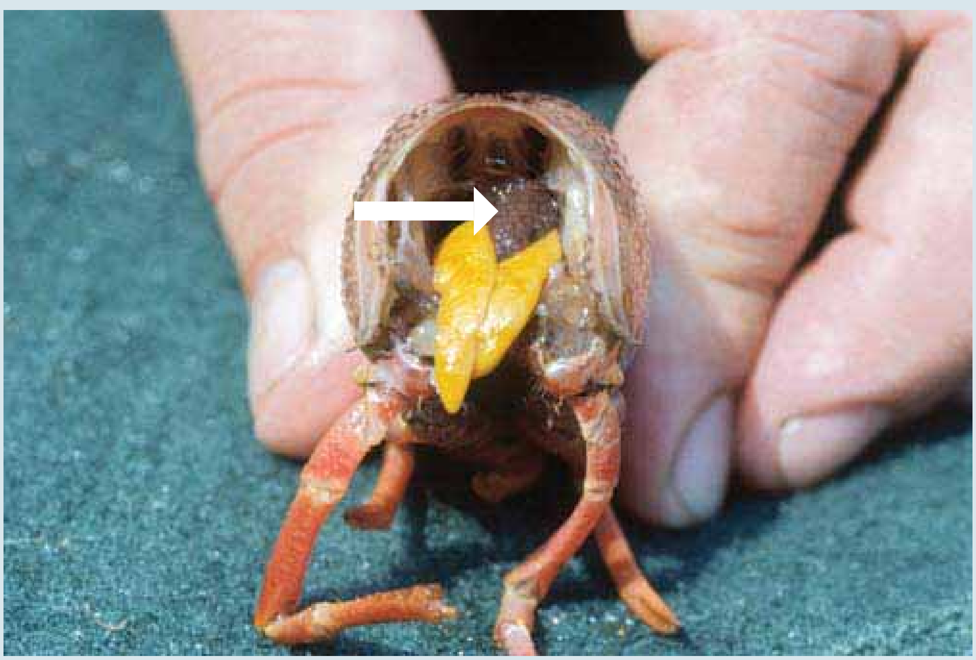
White eggs



Tan eggs

Yellow eggs

Brown eggs



Black eggs

Figure 2.4. Eggs in various stages.

Figure 2.5. Female with hatchlings attached to swimmerets beneath the abdomen.

red swamp crawfish, however, usually occurs in autumn, with minor pulses (or "waves") of hatchlings entering the population later. Extended reproduction and differential growth typically result in a population of mixed sizes in most ponds.

As with all crustaceans, a crawfish must molt or shed its hard exoskeleton to increase in size. Frequent molting and rapid growth occur in production ponds when conditions are suitable. Growth rate is affected by a number of variables, including water temperature, population density, oxygen levels, food quality and quantity, and to a lesser extent by genetic influences. Harvest size is typically reached 3 to 5 months after hatching for fall recruits, but it can be attained in as little as 7 to 9 weeks under optimum conditions.

When males and females molt to a reproductively active stage, growth ceases. Sexually mature individuals exhibit distinct characteristics, including darker coloration, enlarged claws, and hardened sexual structures. Mature males also develop prominent hooks at the base of the third and fourth pair of walking legs. The appearance of mature crawfish in the population usually increases as temperatures rise during late spring. Females will mate (often several times) after molting to a mature form and then begin the process of constructing burrows at the water's edge on levees.

Burrow Ecology

Several studies have provided more detail of crawfish burrows, but, in brief, crawfish cultured in Louisiana dig simple (unbranched), nearly vertical burrows, usually 40 inches or less in depth (Figure 2.6). Burrows serve as refuges from predators and provide moist or humid environments necessary for crawfish to survive through dry periods. Louisiana crawfish have evolved over millions of years to reproduce within the protection of their burrows. Most burrows are built at night and may require several days to complete. Crawfish burrows are usually dug by a single individual, and the burrow diameter is determined by the size of the crawfish. The burrow extends downward into a chamber slightly larger than the diameter of the tunnel.

Water levels in burrows vary with the moisture conditions in the soil. Free water at the bottom of the burrow is more often associated with "trapped" water than the actual water table of the soil. Walls of the burrow and terminal chambers are extensively worked by the crawfish, possibly to ensure good seals. The terminal chamber normally contains wet slush when water is not present, which serves as a humidifier. The entrance of the completed burrow is eventually closed with a mud plug (Figure 2.7), sometimes having a chimney or stack of the soil removed during excavation. Burrow entrances at the water's edge are often associated with natural cover, such as vegetation or woody debris. Over the course of the summer, weathering and covering by vegetation may make the burrow entrance undetectable.

Figure 2.6. An exposed crawfish burrow showing depth and construction.

Burrows usually contain a single female, or sometimes a male and female together, but occasionally they may contain additional crawfish. Successful survival and reproduction within the burrow depends on many factors, such as the severity and length of the dry period, characteristics of the burrow (such as depth, soil type and moisture) and health of the animal. Immature crawfish and crawfish forced to burrow by rapidly dropping water levels may construct shallow burrows that will not have sufficient moisture for survival during lengthy dry periods or drought. Soil types with limited clay content or soil with very high clay content that cracks when dry also may limit crawfish survival while in burrows.

Figure 2.7. Active crawfish burrows will eventually become sealed with a mud plug or cap. With time and weather, and covering of vegetation, the burrow entrance may become inconspicuous.

Once sealed in, crawfish are confined to the burrow until the hard plug that seals the entrance is sufficiently softened by external moisture from flooding or rainfall. Pond flooding, especially when associated with heavy rainfall, facilitates and encourages the emergence of crawfish from burrows.

Crawfish Population Structure

The appearance of new hatchlings in a pond is referred to as "recruitment," and these crawfish usually constitute the bulk of the annual harvest, even when significant numbers of holdover juvenile crawfish are present after flooding. Pond crawfish populations usually include (1) holdover adults from the preceding production season or stocking, (2) holdover juveniles from the preceding season and (3) the current young-of-the-year (YOY) recruits.

The number of age classes and numbers within age classes comprise the overall crawfish density. Crawfish density and population structure have a great impact on overall pond yields and size of crawfish at harvest. The highest densities and most complex population structures usually occur where crawfish have been grown in the same location for several consecutive seasons. In new ponds and ponds held out of production for a year or longer, crawfish density is often lower and the number of age classes is fewer. In these situations, crawfish are often larger and more uniform in size; however, overall yields may be considerably lower.

Population Dynamics

Unlike most aquaculture ventures, where known numbers and sizes of juveniles are stocked, crawfish aquaculture in Louisiana relies on natural recruitment (reproduction) from mature animals (either stocked or already present) to populate the pond. Population density depends largely on broodstock survival, successful reproduction and survival of offspring. Density is mainly influenced by environmental conditions over which producers may have little or no control. Additionally, improper management after autumn flood-up, including low oxygen levels, abundance of predators or pesticide exposure can negatively impact crawfish populations and subsequent production even when broodstock survival and reproduction are high.

Because of this lack of influence and control over population levels, population density and structure is probably the most elusive aspect of crawfish production. Extended reproduction periods and the presence of carryover crawfish from previous season often result in several size or age groups of crawfish being present in a pond at any given time. These various size/age groups are what make up the population structure.

Figure 2.8. Soft, freshly molted crawfish (top) and its cast exoskeleton (bottom).

Although "natural recruitment" in crawfish farming has many advantages, a significant disadvantage is that crawfish producers have little means of accurately controlling or even determining population density and subsequent yield. Available sampling methods are crude and currently include dip net sweeps and use of "test" traps. These methods are highly variable and subject to many sources of bias or error. Producers generally do not have a good assessment of their populations until harvesting is well underway in late spring, after pond temperatures have increased substantially.

Molting

As with all crustaceans, a crawfish must molt or shed its hard external shell ("exoskeleton") to increase in size (Figure 2.8); hence, the growth process involves periodic molting interspersed with inter-molt periods. Approximately 11 molts are necessary for young crawfish to reach maturity. A molt cycle is recognized as having five major stages, but it should be understood that the process is actually continuous. The inter-molt phase is the period in which the exoskeleton is fully formed and hardened. During this phase, crawfish feed actively and increase their tissue and energy reserves. Preparation for molting takes place in the pre-molt stage. This includes the formation of the new, underlying (soft) exoskeleton while a re-absorption of the calcium from the old shell occurs. During the late pre-molt period, crawfish cease feeding and seek shelter or cover.

Molting is usually accomplished in minutes. The brittle exoskeleton splits between the carapace (head) and abdomen (tail) on the back side, and the crawfish usually withdraws by tail flipping. During the "soft" phase that follows, the soft exoskeleton expands to its new, larger dimensions. Hardening (calcification) of the new exoskeleton takes place during the post-molt period, which can be divided into two phases. Initial hardening occurs when calcium stores within the body are transported to the new exoskeleton. Calcium is stored in the body both in soft tissue and for a short period in two hard "stomach stones" or gastroliths (Figure 2.9) located in the head, on each side of the stomach. These stones disappear during the initial hardening period after molting. The second phase of hardening is by absorption of calcium from the water. As crawfish resume feeding, further hardening of the new shell occurs.

Molting is hormonally controlled, occurring more frequently in younger, actively growing animals than in older ones. The

Figure 2.9. Gastroliths are found in the "head" portion of molting crawfish and are associated with temporary calcium stores.

increase in crawfish size during molting, and the length of time between molts, can vary greatly and are affected by factors such as water temperature, water quality, food quality and quantity, population density, oxygen levels and to a lesser extent by genetic influences. Under optimum conditions, crawfish can increase up to 15 percent in length and 40 percent in weight in a single molt.

In culture ponds, frequent molting and rapid growth occur during spring because of warming waters and adequate food sources. The appearance of mature crawfish increases as the season progresses. Rapid increases in temperature (above 80 F) may stimulate onset of maturity at smaller sizes, especially under conditions of overcrowding and food shortages. "Stunting," the condition whereby crawfish mature at an undesirably small size, is a problem in many ponds.

Nutrition

Crawfish have been classified as herbivores (vegetation eaters), detritivores (consumers of decomposing organic matter), omnivores (consumers of both plant and animal matter) and, more recently, obligate carnivores, which means that they "require" some animal matter in the diet for optimal growth and health.

Crawfish have been known to ingest living and decomposing plant matter, seeds, algae, epiphytic organisms, microorganisms and an assortment of larger invertebrates such as insects and snails. They also will feed on small fish when possible. These food sources vary considerably in the quantity and quality in which they are found in the aquatic habitat. Living plants, often the most abundant food resource in crawfish ponds and natural habitats, are thought to contribute little to the direct nourishment of crawfish. Starchy seeds are sometimes consumed and may provide needed energy, but intact fibrous plant matter is mostly consumed when other food sources are in short supply. Aside from furnishing a few essential nutrients, living plant matter provides limited energy and nutrition to growing crawfish.

Decomposing plant material, with its associated microorganisms (collectively referred to as detritus) is consumed to a much greater degree and has a higher food value. The ability of crawfish to use detritus as a mainstay food item, however, appears to be very limited. Fortunately, in a typical crawfish pond environment numerous animals besides crawfish rely on the microbe-rich detritus as their main food source. Mollusks, insects, worms, small crustaceans and some small vertebrates depend on detritus (Figure 2.10) and, when consumed by

Figure 2.10. A myriad of invertebrates in crawfish ponds, fed by decomposing plant fragments (top), furnish crawfish with the high quality nourishment needed to sustain maximum growth.

crawfish, these animals furnish high-quality nutrition. Scientists have realized that for crawfish to grow at their maximum rate, they must feed to a greater extent on these high-protein, energy-rich food sources.

Sufficient evidence has been established to indicate that although crawfish must consume high-protein, high-energy sources to achieve optimum growth, they can sustain themselves for some time by eating intact and decomposing plant sources and even bottom sediments containing organic debris.

Supplemental feeds are not routinely provided to crawfish aquaculture ponds. Commercial culture of crawfish relies on a self-sustaining system for providing nourishment to crawfish, as occurs in natural habitats where crawfish are abundant. An established (or at least encouraged) vegetative forage crop provides the basis of a complex food web (Figure 2.11) that ultimately fuels production of crawfish with harvests that typically average 400-600 pounds per acre and can often exceed 1,000 pounds per acre.

Plant fragments from the decomposing vegetation provide the "fuel" that drives a detrital-based production system, with crawfish at the top of the food web. As a result, the main means of providing nutrition to crawfish in aquaculture is through establishing and managing a forage crop. Ideally, once ponds are flooded in the fall, a constant and continuous supply of plant fragments fuels the food web from which crawfish derive their nutrition. (Also see chapter 5.)

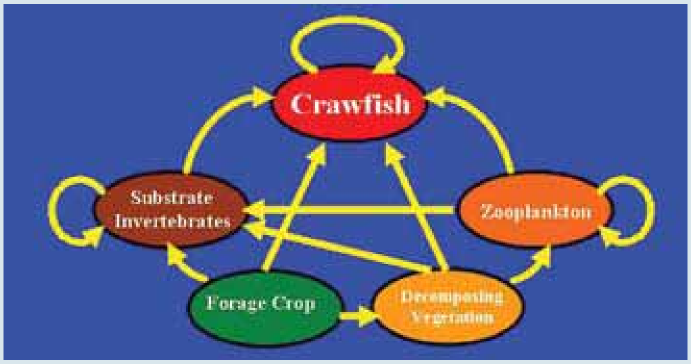


Figure 2.11. A simplified diagram of the nutrient pathways of the food chain in crawfish ponds, with the forage crop serving as the principal fuel and crawfish at the top of the food chain.

Chapter 3. Crawfish Production Systems

Commercial culture of Louisiana crawfish relies on earthen ponds, with production methods that are much less intensive than those found in other forms of aquaculture. The methods used for crawfish aquaculture is little more than limited control of the environmental conditions under which these animals evolved.

Red swamp and white river crawfish are naturally adapted to habitats with seasonal flooding and drying, where the dry period usually occurs from summer into autumn. The life cycle of crawfish is well suited to fluctuating periods of flooding and dewatering. In their natural, river or swamp habitats, sustained periods of river overflow permit crawfish to feed, grow and mature. Temporary dewatering, in both natural habitats and crawfish ponds, promotes aeration of bottom sediments, reduces abundance of aquatic predators and allows for establishment of vegetation that serves as cover for crawfish and the source of important food resources when water returns. Crawfish survive the dry intervals by digging or retreating to burrows where they can avoid predators, acquire moisture necessary for survival and reproduce in safety.

Current farming practices are based on the annual water cycles and conditions to which these crawfish have become adapted over millions of years. Flooding and draining of crawfish ponds mimic the natural flooding and drying cycle in Louisiana's Atchafalaya River basin. The control achieved under farming conditions provides optimal timing of these events and allows crawfish producers to positively influence water quality, food resources and other factors within their ponds. As with natural ecosystems, crawfish aquaculture relies on natural reproduction. No hatcheries or nurseries are required. Crawfish in forage-based culture ponds, as in the wild, depend on a naturally available food web for nourishment. Supplemental feeding is not a common practice; it has not yet been shown to predictably increase yields or size of crawfish at harvest.

Crawfish are grown in shallow earthen ponds 8 to 24 inches deep. Relatively flat, easily drained land, with suitable levees, is required for production, harvesting and management of vegetation (Figure 3.1). Crawfish are cultured in areas where the soil has sufficient clay to hold water and accommodate burrow construction. Water requirements for crawfish production are similar to those for other freshwater aquaculture ventures, with the possible exception of water quantity. Ponds are flooded in the fall and drained in the spring, and because of the oxygen demand from decaying vegetation, additional water exchanges are sometimes necessary.

Figure 3.1. Successful crawfish production requires flat soils with sufficient clay content. Lands suitable for rice or sugarcane production are often also well-suited for crawfish.

Figure 3.2. Specialized equipment and supplies are essential for commercial success.

Equipment requirements for culturing crawfish include irrigation systems, harvesting equipment (boats, traps, sacking tables, etc.) and agricultural implements to establish the forage crop and maintain levees (Figure 3.2). Access to sufficient labor and alternative marketing outlets are essential for successful commercial operations.

Although crawfish aquaculture ponds are sometimes categorized by pond type or dominant vegetation, a better strategy is perhaps to categorize ponds by two basic production strategies. (See summary of production strategies in Table 3.1) One strategy is monocropping, or monoculture, in which crawfish are the sole crop harvested, and production typically occurs in the same physical location for several production cycles or even longer.

A second strategy is the crop rotation system, in which rice, and sometimes soybeans or other crops, are raised in rotation with the crawfish. In these systems, crawfish are either rotated with rice in the same physical location year after year, or crawfish are cultured in different locations each year to conform to normal field rotations of the other crops.

Although these two major management strategies have many similarities, different production goals dictate different management concerns.

Monocropping Systems

Crawfish monoculture or "single-crop" systems is the production method of choice for many small farms or where marginal lands are available and unsuited for other crops. Permanent ponds, or sites devoted to at least several consecutive production cycles, are typically used for this strategy. Pond size and production input for this approach range from large (greater than 300 acres) impounded wetlands with little management to small (less than 15 acres) intensively managed systems. The main advantage of a monocropping strategy is that producers

Table 3.1. Summary of Major Crawfish Production Strategies With Common Practices by Month.

Months	Crawfish Monoculture	Crop Rotational Systems	
		Rice-Crawfish-Rice	Rice-Crawfish-Fallow or (Rice-Crawfish-Soybean)
Jul - Aug	Forage crop planted or natural vegetation allowed to grow	Rice crop harvested in August and stubble managed for regrowth	Rice crop harvested and stubble managed for regrowth
Sep - Oct	Pond flooded and water quality monitored and managed	Pond flooded in October and water quality monitored and managed	Pond flooded in October and water quality monitored and managed
Nov - Dec	Harvest when catch can be economically justified	Harvest when catch can be economically justified	Water quality monitored and managed
Jan - Feb	Crawfish harvested 2-4 days per week according to catch and markets	Crawfish harvested 2-4 days per week according to catch and markets	Crawfish harvested 2-4 days per week according to catch and markets
Mar - Apr	Crawfish harvested 3-5 days per week according to catch and markets	Crawfish harvested 3-5 days per week until late April, then pond drained and readied for planting	Crawfish harvested 3-5 days per week according to catch and markets
May - Jun	Crawfish harvested until catch is no longer justified; then pond drained	Rice planted in May and rice crop managed for grain production	Pond drained and soybeans planted or harvest proceeds as long as catch is feasible; pond then drained and left fallow
July - . . .	Repeat cycle	Repeat cycle	Harvest soybeans in October, plant rice in March/April, stock crawfish in May, repeat cycle

can manage for maximum crawfish production without the various concerns associated with other crops, such as pesticide exposure, seasonal limitations and other constraints associated with crop rotation.

Crawfish yields in monocropping systems typically range from less than 200 lb/ac in large, low input ponds to more than 1,200 lb/ac with intensive management. Some ponds have yielded in excess of 2,500 lb/ac. In many "permanent" crawfish ponds, yields tend to increase annually up to three or four years of consecutive production.

Additionally, smaller ponds usually have higher yields than larger ponds, especially when marketing smaller, lower-value crawfish is not a problem. Earlier and more intense harvesting is often justified in older, permanent ponds because of the dense populations and increased numbers of holdover crawfish. This practice is economically important because earlier harvests are almost always associated with higher prices.

Figure 3.3. When crawfish densities become too great, growth slows or ceases even in the presence of abundant forage and good water quality.

Although the monoculture approach offers several advantages, it also has disadvantages. These often include: (1) the need to construct dedicated ponds, whereas with rice/crawfish rotational cropping, the established rice field serves the purpose; (2) land, overhead and operating costs must be amortized over one crop only; and (3) crawfish overcrowding frequently occurs after several annual cycles, particularly in smaller ponds; therefore, yields become composed of small (stunted), low-priced crawfish that are difficult to market (Figure 3.3).

Production schedules vary within and between geographical regions, but permanent monocropping ponds generally follow the schedule presented in Table 3.1. Since crawfish populations are self-sustaining, stocking is usually needed only in new ponds, when a pond has been idle for a year or more or after extensive levee renovation. Subsequent crawfish crops rely on holdover broodstock from a previous cycle. Ponds are stocked from 40 lb/ac to 80 lb/ac of adult red swamp crawfish sometime between early April and early July (Figure 3.4). Stocking dates and rates are usually dictated by the availability and cost of mature crawfish.

Ponds are thoroughly drained, ideally beginning no sooner than two to three weeks after stocking. Cultivated or volunteer vegetation is established in pond bottoms during the summer when ponds are dewatered. The vegetative crop serves as the main nutritional input for the following crawfish season. Rice is the standard cultivated crop, and emphasis is on forage (stem and leaf) production. Grain, if present, is not harvested in crawfish monocropping systems. After reflooding in autumn, producers monitor the crawfish population with baited traps and initiate harvesting when catch and marketing conditions justify the labor and expense. Harvesting continues (often in intermittent intervals) until ponds are drained the following summer, and the cycle is repeated.

Figure 3.4. Stocking a rice field pond with crawfish broodstock.

Crop Rotational Systems

Crawfish may be cultured in two basic crop rotation systems. One is rice-crawfish-rice, and the other is rice-crawfish-fallow/soybean. In both strategies, crawfish culture follows the rice harvest, and the forage crop used for growing crawfish is the crop residue and re-growth of the rice stubble after grain harvest. Advantages of these rotational strategies include efficient use of land, labor and farm equipment. Moreover, some fixed costs and the cost of rice establishment can be amortized over two crops instead of just one.

Rice-crawfish-rice

This approach takes advantage of the seasonality of each crop to obtain two crops in one year. Rice is grown and harvested during the summer, and crawfish are grown during autumn, winter and early spring in the same field each year. (See Table 3.1). As with monocropping systems, crawfish are only stocked initially. They are introduced directly into the rice crop about 4 to 7 weeks post-planting. Following grain harvest, the residual rice crop is usually fertilized with a nitrogen-based fertilizer and irrigated, if necessary, to achieve a ratoon crop (regrowth) of forage (Figure 3.5). Subsequent to the fall "flood-up," management practices are similar to those of a monocropping system with the exception of a shortened growing and harvesting season to accommodate the establishment of the next rice crop.

A major disadvantage with this rotational strategy is that usually neither crop can be managed to yield maximum production. Rice yields in the South are maximized when rice is planted in early spring. Draining the crawfish pond prematurely to accommodate rice establishment decreases total crawfish yield. Pesticide use is another major management consideration, and it is a particular constraint with this production strategy. Crawfish and rice yields vary and depend on management emphasis. Those systems managed mainly for crawfish can expect crawfish yields similar to well-managed monocropping systems but at the expense of rice yield and vice versa.

Rice-crawfish-fallow (or rice-crawfish-soybean)

The second major rotational strategy employs crawfish in a rotational system of rice and sometimes soybeans. The major difference in this rotation strategy is that rice is not typically cultivated in the same field during consecutive years, to aid in the control of rice diseases and weeds for maximum rice yield. As with a rice-crawfish-rice rotation, however, crawfish culture follows rice cultivation; therefore, crawfish production does not occur in the same physical location from one year to the next. (See Table 3.1). Under this method, if soybeans or another crop is incorporated, three crops per field can be realized in two years. Depending on a variety of factors, some producers may elect to plant a different crop (hay, pasture or grain sorghum) or simply leave the field fallow instead of planting soybeans after the crawfish season ends.

The field rotational approach requires sufficient land resources to allow staggered crops in different fields within a farm, and it is the preferred cropping system for larger commercial rice farmers. This cropping strategy comprises much of the acreage used to grow crawfish in Louisiana. It has several advantages over rotation within the same field. Each crop can be better managed, and the crawfish production season can be extended. For example, in lieu of draining crawfish ponds in early spring to plant rice, crawfish harvest can continue until late spring or early summer when the pond is drained to plant soybeans (or other crops), or longer if plans are to leave the field fallow. Furthermore, by rotating physical locations each year, overpopulation of crawfish is rarely a problem, and crawfish size often is larger because of lower population densities.

Crawfish yields under this management approach are not commonly as high as with monocropping systems, but with proper management, yields can routinely exceed 900 lb/ac. Some disadvantages of this rotational strategy relative to crawfish production in permanent or semi-permanent ponds are: (1) the need to restock every year, (2) routine low-population densities and (3) frequently, a late-season harvest when prices are in decline and marketing is more difficult because of abundant supplies.

Figure 3.5. In many situations, crawfish can be produced on the same land as a rice crop, although usually with somewhat lower yields.

Chapter 4. Pond Location, Design and Construction

Pond location, design and construction are the most important physical factors for successful crawfish production. Proper design and construction give the crawfish farmer better control over flooding, drainage, forage management, water circulation and harvesting. Although management practices can be easily changed from year to year, trying to change ponds that were poorly designed and improperly constructed can be expensive. Seek advice from your local LSU AgCenter extension agent and area United States Department of Agriculture (USDA) Natural Resources Conservation Service engineer prior to beginning construction.

Location

Crawfish ponds should be located in flat, open areas, and the soils should have sufficient amounts of clay. Adequate water sources should be available. Clay loams, sandy clay loam and silty clay loams are satisfactory soil types. A clay soil is necessary to hold water and to maintain the integrity of crawfish burrows. Generally, soils that can be rolled into a ball have enough clay for crawfish culture. Elevations must be sufficiently high to allow the pond bottom to remain above water levels in the surrounding drainage ditches and canals (Figure 4.1).

Figure 4.1. Sufficient elevation to allow for good drainage is required for crawfish pond management.

For rice-field ponds, sites are usually limited to existing rice fields. Even so, consideration of which fields will be placed in crawfish production is important. Because of the labor intensive operations of crawfish farming, many rice farmers typically commit only 10 percent to 50 percent of their total rice acreage to crawfish. Often the best producing rice fields are not selected for rotation with crawfish. It is important to select rice fields with adequate all-weather access because crawfish harvesting and pond management are daily activities and often occur during wet weather. Fields selected for crawfish production should have accessible and economical water supplies because the water requirements for crawfish farming are higher than for rice production.

Field size and layout may be an important consideration when producing crawfish on rice acreage. Trapping lanes are more efficient when long and straight, and levee crossings should be kept to a minimum. Limited access for vandals and thieves may be an important consideration. Consideration of the positioning of fields destined for crawfish production may also be important from a pesticide perspective. Positioning of crawfish ponds between producing agronomic fields, or downwind from a field where aerial application of an insecticide is planned is not prudent.

Design and Construction

A number of considerations should be taken into account when constructing permanent crawfish ponds. Many of these also apply to rice fields that are intended for crawfish production. Perimeter levees should have a core trench cleared of debris to prevent water seepage. The minimum perimeter levee base should be 9 feet wide to prevent leakage from the burrowing activities of the crawfish. A levee system 3 feet high is adequate to contain the minimum 8 to 12 inches of water necessary to cultivate crawfish. The land should have no more than a 6-inch fall between perimeter levees. Otherwise, the area should be leveled or divided into two or more ponds. Ponds with steep elevations and resulting depth variations hinder forage establishment, restrict water management techniques and reduce harvesting efficiency.

Wide and deep interior ditches inside crawfish ponds, which are usually adjacent to large perimeter or large baffle levees, should be avoided where possible. These deep areas provide a pathway of least resistance for water flow that can reduce circulation in other areas of the pond, potentially causing poor quality and reduced catch in areas away from the ditches. Additionally, interior ditches are difficult to drain, and they may serve as a refuge for predatory fish after ponds are drained. Interior or baffle levees are constructed to guide water through the pond for proper aeration and to help maintain proper water quality (Figure 4.2).

Figure 4.2. Baffle levees are often comparable to typical rice field contour levees. The key is to direct the flow of water through the pond to avoid "dead" areas with little or no oxygen.

Baffle levees are built about 6 feet wide at the base. They should extend a minimum of 6 inches above the expected water level for the pond. If the part of the baffle levees above the water line is not substantial enough, settling and erosion will cause the levees to breach in one or two years. Baffle levees should be spaced 150 to 300 feet apart to facilitate water circulation. Core trenches in the baffle levees are not necessary. A recirculation canal outside the perimeter levee and a re-lift pump will aid in water circulation and minimize water discharge (Figures 4.3 and 4.4). Ponds designed to recirculate water are important in areas where the quality of the surface water supply fluctuates or where well water must be pumped from great depths at great cost. (See chapter 6, "Water Quality.")

Figure 4.3. Many crawfish ponds can be adapted to allow for circulation using one or more re-lift pumps.

Drains should be matched with the pond size, pumping capacity and projected rainfall (Figure 4.5). Two 10-inch drains are sufficient to drain a 20-acre pond. Ponds must allow vehicle access in wet and dry conditions and allow efficient use of harvesting equipment.

Most often, crawfish ponds in a rice-crawfish rotational system use established rice fields where the field lay out and irrigation systems are fixed. Some modifications of the field may be necessary, however, for best results with crawfish. Small levees that are adequate for rice production in shallow waters (less than 5 to 6 inches deep) are not adequate for crawfish production where water levels are usually maintained at 8 to 16 inches. Larger levees are especially critical for the perimeter, which hold in water. Whereas rice production requires a water holding period of 8 to 10 weeks, crawfish ponds are usually flooded for 7 to 10 months. Settling, erosion, burrowing rodents and crawfish burrowing can take their toll on small levees. Therefore, rice fields destined for crawfish production usually require much taller and wider levees. It should be noted though that levee construction/reconstruction should occur before introduction of crawfish broodstock because levee renovation after crawfish have burrowed can reduce broodstock survival and reproduction.

Levees can also act to keep flood waters out of a crawfish pond at times. Breached levees from flood waters can disperse crawfish out of the pond and introduce unwanted fish into the pond. With electronic laser leveling, some rice fields have become very large with few or no interior levees. If too large, these fields may possess a ratio of linear levee to total pond area that is too large for optimal reproduction, because crawfish use the levees as burrowing sites. Conversely, the presence of too many interior levees potentially provides excess reproduc-

Figure 4.4. When ponds are extremely level, recirculation can be accomplished using commercially available or shop-built paddlewheel aerators.

Figure 4.5. Drains must have sufficient capacity to lower ponds over a short period of time.

tive burrowing area and can lead to overpopulation and stunted crawfish. The optimal levee-to-pond area ratio has not been determined and varies with geographic location and other conditions.

Rice-field water irrigation is usually designed to achieve efficient water output with little concern for maximizing oxygen content of the water. Therefore, it is recommended that water discharge outlets on irrigation wells be modified to include aeration screens to maximize oxygen input to provide for the highest quality of water in fields where crawfish are to be grown.

Best Management Practices for Crawfish Pond Construction

A set of best management practices (BMPs) for crawfish production has been developed in cooperation with the USDA Natural Resources Conservation Service (NRCS). (See summary in Table 4.1) These practices seek to minimize erosion, reduce the amount of contaminants (nutrients and pesticides) in effluent discharges and maximize the benefit to wildlife.

Table 4.1. Summary of United States Department of Agriculture National Resource Conservation Service (NRCS) Best Management Practices for Crawfish Pond Design and Construction.

Conservation Practice	NRCS Code	Comments
Access road	560	Necessary for daily transportation to crawfish ponds for water management, forage management, harvesting and marketing crawfish. May impede natural runoff. May contribute to siltation if not properly vegetated. May reduce wetland habitat.
Brush management	314	May be required to plant forage and to develop harvesting lanes. Physical removal may cause temporary turbidity problems. Labeled use of herbicides would not have a significant environmental impact.
Channel vegetation	322	Turbidity caused by unvegetated channels may contribute to sedimentation problems. Vegetated channels help turbidity problems and improve water quality pumped into ponds.
Crop residue use	344	Natural vegetation may be allowed to grow before preparing for forage production to reduce erosion during interim of draining and planting forage. Provides habitat for wildlife. Cover improves soil moisture and should improve conditions for crawfish in burrows.
Filter strips	393	Provide a means of reducing sediment in inflow and discharge water where practical. May reduce soil erosion.
Fish pond management	399	Crawfish ponds used to produce crawfish commercially. Depth and forage production differ from typical fish ponds. Provides positive impact on the environment. Provides habitat for many forms of wildlife, such as wading birds, waterfowl and many furbearers.
Irrigated field ditch	388	Another effective irrigation tool that promotes good water management and conservation. Provides pathway for water from source to ponds.
Irrigation water management	449	Planned irrigation, flooding and draining to manage forage and crawfish.
Wells	643	Well water recommended over surface water.
Wetland development	657	Flooded crawfish ponds greatly benefit and improve the quality of the water entering and exiting the field in most cases. Crawfish ponds and production have a positive impact on the environment.
Wildlife wetland	644	Crawfish ponds provide more than 120,000 acres of manmade wildlife wetland habitat that greatly benefits waterfowl, wading birds, gallinules, shorebirds, furbearers, reptiles, amphibians and numerous invertebrate animals that benefit other species of wildlife.

Crawfish farming practices are based on annual hydrological cycles and conditions, to which the crawfish have become adapted – namely, seasonal flooding and drying, with the dry period usually occurring during the summer. Pond inundation, or flooding, begins the chain of events that establishes the environment from which crawfish obtain most of their nutrients. As indicated in Chapter 2 under nutrition, crawfish are not routinely fed pelleted rations. Rather, the production strategies in Louisiana and other southern states rely on a forage-based system for providing nourishment to growing crawfish. (Also see supplemental feeding in Chapter 9.)

A forage-based production system benefits crawfish indirectly by supporting a complex ecological community of invertebrates, which the crawfish then consume as high quality food sources. The invertebrate community that is so important to crawfish relies on a continual influx of plant fragments that are in turn consumed by bacteria and other microorganisms. Put simply, the forage crop serves as the fuel for a food web, with crawfish at the top of the food web.

Careful Management of Forages

Because commercial crawfish production requires high crawfish densities, and because flooding duration is long (7-10 months), the forage-based food chain becomes highly used and requires careful management for maximum crawfish harvests. High crawfish yields without supplemental feed require ample quantities of aquatic invertebrates in the pond, fueled by a constant supply of plant fragments.

A continual supply of vegetative matter for decomposition is necessary throughout the production season to feed the invertebrate population. This requires a forage crop that yields small portions of its material on a consistent basis over the duration of the season. Too much vegetative input into the system at one time is wasted because it cannot be stockpiled; thus, a large portion deteriorates without being consumed. Also, excess contribution at one time leads to premature depletion of the food resource and can cause low oxygen conditions. Too little vegetative detritus can result in actual food shortages for the organisms that crawfish rely on as high quality food items and, therefore, food shortages for crawfish.

Crawfish farming, as practiced in Louisiana, requires a forage crop that provides plant matter to the underwater food web consistently throughout the growing season. In general, voluntary stands of vegetation perform this task poorly. Terrestrial grasses make for a poor crop because much of the stand is killed upon flooding, negatively affecting water quality and providing short-lived detrital resources (Figure 5.1). Because of the adaptations of rooted aquatic and semi-aquatic plants such as alligatorweed (*Alternathera philoxeroides*) (Figure 5.2), smartweed (*Polygonium* spp.) and others, fragmentation is usually inconsistent and often seasonal. Much of the vegetative biomass of hardy aquatic plants normally remains alive and above water and is unavailable to the food web except for seasonal events such as killing frosts, which often make it available in excess quantities and at times (winter) when it can be least utilized.

Figure 5.1. Terrestrial vegetation that is killed upon flooding breaks down quickly, causes water quality problems and provides little fuel for the natural food web that supports crawfish harvests.

Despite the inadequacies of individual plant species in a volunteer stand, the right mixtures of native plants can have a complementary effect and do occasionally produce acceptable crawfish yields. With voluntary stands of vegetation, however, the appropriate mixture of species is very difficult to obtain on a consistent basis. Furthermore, some native plants tend to become so thick they impede harvesting efforts and/or efficiency. Pond warming during spring, and often water circulation, can be slowed by thick stands of plants. Moreover, many voluntary species are considered noxious weeds and are undesirable in fields where agronomic crops will be grown during subsequent years.

Planted agronomic crops routinely have been the most effective forage resources for crawfish ponds. They are effective partly because these plants exhibit the desired characteristics under the long-term flooded condition of a crawfish pond and partly because adequate stands of vegetation are achievable and predictable when recommended management practices are followed.

Figure 5.2. Naturally occurring aquatic plants such as alligatorweed can provide for some crawfish production, but they generally cannot generate the yields realized with rice or sorghum sudangrass.

Figure 5.3. The growth and decay characteristics of rice make it suitable for use as a forage in crawfish ponds.

Other Benefits from the Forage Crop

Apart from supporting natural food production, native and cultivated plants can benefit crawfish ponds in other ways. (1) Forages provide refuge and hiding places for crawfish to escape predators and help to minimize cannibalism. (2) Standing plants provide vertical substrate that allows crawfish to escape the bottom, utilize the water column and reach the pond surface during periods of low oxygen. (3) Forages also provide substrate, or attachment surfaces, for epiphytic organisms and invertebrates that comprise part of the crawfish's diet.

Rice (*Oryza sativa*) has become the standard forage crop for the industry (Figure 5.3). Because of its semi-aquatic nature, rice tends to persist well in flooded crawfish ponds, yet it furnishes plant fragments to the detrital pool in a consistent manner. Sorghum-sudangrass hybrid (*Sorghum bicolor* x *S. sudanense*) is also used successfully (Figure 5.4). Millets (browntop, Japanese, proso and pearl cultivars), grain sorghum and soybean stubble also have been examined as possible forage crops, but all these plants demonstrate limited potential for crawfish production when compared to rice or sorghum-sudangrass.

Agronomic plant type and management considerations for maximum yield in crawfish ponds depend on the type of culture system used for growing crawfish. Although basic cultural requirements and practices for producing crawfish are similar regardless of management approach, different production goals dictate different management concerns. This consideration particularly applies to the forage crop and its management. Information regarding recommended practices for planting and management of forage crops can be found in publications such as the Louisiana Rice Production Handbook (Pub. 2321) or by contacting your local LSU AgCenter extension agent.

Monocropping Systems

In crawfish monocropping systems, choice of plant species/variety and time of planting are the most important considerations regarding forage management. (Also see Management Considerations in Chapter 7.) Aside from relying on voluntary vegetation, choices for maximum benefit are limited mainly to rice or sorghum-sudangrass hybrid, and the choice usually depends on personal preference and logistical considerations. Rice is the most widely used of the two, and variety selection is primarily based on forage characteristics rather than grain traits. Unless waterfowl hunting is part of the overall management goal, grain production in the crawfish forage crop is not desirable.

Until 2004, rice variety selection for use in crawfish ponds had been limited to those varieties developed for grain production. Rice breeders have consistently developed rice varieties for grain production that have high grain-to-forage ratios, are shorter in plant height and are earlier maturing – characteristics that, although desirable for high-yielding grain crops, are less desirable in a crawfish forage crop. Desirable traits for rice used in crawfish ponds include high forage biomass production, low-temperature tolerance, longer maturity cycle, high resistance to lodging, slow senescence (breakdown) rate, disease resistance and propensity for plant re-growth in spring.

In 2004, the LSU AgCenter released the first rice cultivar developed specifically for use in crawfish monocropping systems. "Ecrevisse" was the culmination of years of screening and evaluation of rice genotypes originating around the world, and selection of one line that was further improved (purified) under Louisiana's growing conditions. This new variety exhibits much greater forage biomass production, better persistence under the extended flood conditions of a crawfish pond and has a greater propensity for post-winter regrowth than the commonly used domestic varieties (Figure 5.5). Because of the selection criteria used and the methods employed for further development of this variety, there was an inherent selectivity for disease resistance and adaptability to South Louisiana's soil and environmental conditions. Therefore, until a better variety is found, this new variety should be the hands-down choice for establishing a rice forage crop in crawfish monoculture ponds in Louisiana. Ecrevisse is almost certainly limited to crawfish monocropping systems, however, because it is a short grain rice and exhibits poor milling traits, making it less desirable for use in grain markets.

Selection of rice varieties other than Ecrevisse for establishment in crawfish monocropping ponds is currently limited

Figure 5.4. Sorghum-sudangrass, when managed properly, can be a suitable alternative to rice as a forage crop in crawfish ponds.

Figure 5.5. Ecrevisse, the first rice variety specifically developed for crawfish production, as it appeared in late spring in a commercial crawfish pond when planted the previous summer.

to commercially available high grain-yielding varieties. Recommendations from commercially available varieties are scant because few comparative studies have been made regarding their suitability in crawfish ponds. New varieties are released and adapted so often that it is impractical to investigate thoroughly each one within the different regions where crawfish are grown. In general, those varieties that are well-adapted to local conditions, are taller, have a longer maturity cycle, tiller well, produce abundant forage biomass and senesce slowly are likely to be the best choices for planting in crawfish ponds. In theory, supported only by preliminary research, it may be beneficial to mix several varieties when planting in crawfish ponds. Differences in post-flood characteristics of different varieties, such as fragmentation rate, crop persistence and re-growth potential may provide detrital material to the pond on a more consistent and extended basis than a forage crop composed of only a single variety.

It has also been demonstrated that sorghum-sudangrass, commonly used by cattlemen for grazing and hay, is a well suited alternative forage crop for crawfish monocropping systems. It grows rapidly, can produce nearly twice the amount of forage biomass as rice, is very hardy and drought resistant and may prove more reliable in some cases than rice when a stand must be established in late summer. This crop, if managed properly, also exhibits good persistence in crawfish ponds with consistent fragmentation of material well into the season. One of the main benefits of sorghum-sudangrass over rice is that it does not require as much moisture for optimum growth. An adequate rice crop can rarely be achieved without some irrigation during the summer growing phase in Louisiana. Conversely, sorghum-sudangrass may need little or no irrigation and, in fact, cannot tolerate saturated soils for an extended period while in its early growth stages. Another potential benefit of sorghum-sudangrass over rice is that it has a later recommended planting date. Because of its rapid growth potential, when the optimal window for rice establishment has passed, forage stands can often still be established (or salvaged) by planting sorghum-sudangrass.

Regardless of which agronomic crop is chosen for use in crawfish monocropping systems, time of planting is extremely important. For best results, when waterfowl hunting is not a consideration, it is essential to plant early enough in the summer to achieve maximum vegetative growth, but not so early that the plant reaches full physiological maturity. A forage crop that matures or "fills grain" prior to the onset of winter tends to senesce more rapidly (Figure 5.6), often resulting in early depletion of the forage resource and subsequent stunting before the crawfish season's end. In South Louisiana, the most appropriate planting time for rice for crawfish forage is during the first two weeks of August. For sorghum-sudangrass, optimum planting time is generally in the last two weeks of August.

Recommended planting dates tend to be earlier in more northerly areas. If a crawfish producer anticipates flooding early (prior to mid-October) or grazing or baling of the crop, earlier planting of sorghum-sudangrass should be considered. When waterfowl management is an important component of the farming practice and seed formation in the crawfish forage crop is desired, species selection and/or planting dates may need to be altered. In most situations, however, it is difficult to manage for maximum benefits in the crawfish forage crop while managing for waterfowl hunting.

Adequate stand establishment is another important aspect of forage management. Even under the best of situations, early depletion of the forage resource can occur, especially with high populations of crawfish (Figure 5.7). Nevertheless, to ensure maximum benefit from the forage crop, starting with an ample stand of forage is essential. Regardless of plant type chosen, when dry-seeding forage for crawfish, good stands are easier to achieve in well-tilled seedbeds. Water seeding is also a common method for the commercial planting of rice; however, achieving proper stands can be difficult with this method during the sum-

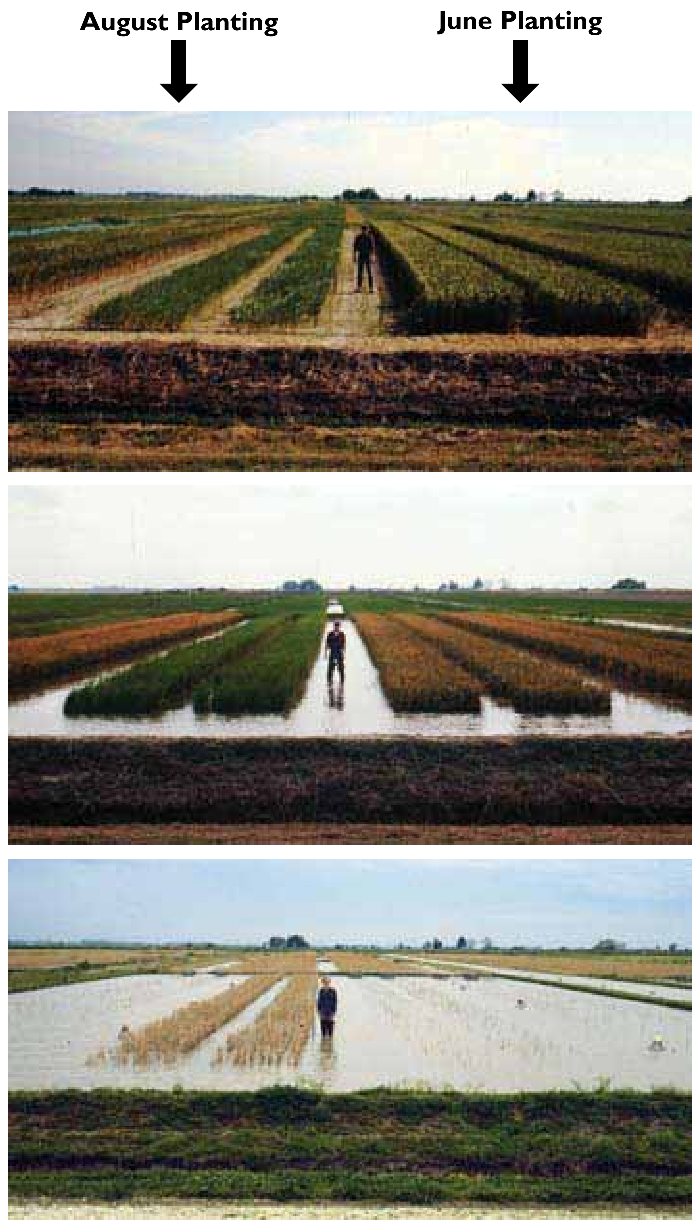


Figure 5.6. Rice planted too early in crawfish monocropping systems, whereby the plant reaches maturity (fills grain), tends to become depleted prematurely as noted in this LSU AgCenter experiment (June planted rice on right, August planted rice on left).

Recommended Crawfish Forage Planting Times in Monocropping Systems

Rice - Optimum planting time for crawfish forage in southern Louisiana is the first two weeks of August

Sorghum-sudangrass - Optimum planting time in southern Louisiana is the last two weeks of August

Figure 5.7. A forage-depleted pond. This situation is often common by late winter and early spring.

mer heat. High water temperatures can impede germination or stifle survival of young seedlings.

Water (or moisture) management is an important consideration for both water- and dry-seeded fields. Rainfall after planting is the preferred means of obtaining and maintaining moisture, but in the absence of timely rains, irrigation may be needed. As with water seeding, standing puddles of water after planting can contribute to poor stands of forage in dry-seeded fields. Permanent, but shallow, floods usually can be established in rice forage crops when the rice plants are tall enough (2-4 weeks after planting) to withstand standing water. If the pond contains minimal amounts of terrestrial weeds that would not contribute to water quality problems when flooded, a shallow flood is desirable. Water levels can be slowly increased as the rice grows until full flood depth is reached in the fall. Establishment of the permanent flood in crawfish ponds planted with sorghum-sudangrass, however, should be delayed until the forage crop has stopped growing or the optimal flood-up date (typically October 15) is reached.

Dry-seeding Recommendations

For dry seeding of rice, 75 lb/ac to 90 lb/ac of seed are recommended for drill planting, and 90 lb/ac to 120 lb/ac of seed are recommended for dry broadcasting. Sorghum-sudangrass can be planted at 20 lb/ac to 25 lb/ac if drilled or 25 lb/ac to 30 lb/ac if dry broadcast in well-tilled seedbeds. Dry broadcast-seed of both rice and sorghum-sudangrass should be lightly covered (0.25 to 0.5 inch) with harrow or other similar equipment for best results. Depth of drill-planted seed depends largely on soil type and moisture content, and LSU AgCenter extension service recommendations should be followed for proper seeding depth.

With any agronomic forage crop and with most soil types, some fertilization will likely be needed for optimum forage production. Normally, on lighter soils at least 40-60 units of nitrogen (N) and a lesser amount of phosphorus (P) and potassium (K) are usually required, but a soil test is recommended for determining exact needs. Other soil amendments, such as agricultural lime, are sometimes needed but depend on several factors, including forage crop, soil type and chemistry and water characteristics. They should be determined by soil (and sometimes water) testing. Soil and water samples can be analyzed by the LSU AgCenter's Soil Testing and Plant Analysis Laboratory for a nominal fee. Contact your local LSU AgCenter extension office for instructions on submitting soil and water samples for analysis.

Pesticide management in the forage crop should be dictated by needs on a pond-by-pond basis. In crawfish monocropping systems where grain production is not the desired outcome, chemical weed control should only be undertaken when weed type and density threatens the health of the forage crop. The presence of some weeds in the forage crop is not detrimental and may even be desirable if the weeds act in a complimentary nature to the forage crop. For example, limited amounts of alligatorweed, well dispersed in a pond, are often beneficial. As the rice crop diminishes during the later part of the season, alligatorweed usually thrives in the warming water, providing shelter, substrate and some food value to the pond.

Insects, especially fall army worms, and diseases also can affect forage crops. Very few pesticides, however, can be used in crawfish ponds. Pond flooding can be an effective alternative treatment for armyworms in rice but this strategy is usually not a suitable option in sorghum-sudangrass. Aside from the chemical label restrictions linked to pesticide use, concerns also are associated with the exposure of crawfish to many chemical compounds. Although the crawfish are likely protected within the burrow from most legal pesticide applications on dry ground, extreme caution and knowledge should be exercised when making any pesticide application. The LSU AgCenter extension service or other knowledgeable professionals should be consulted when questions about pest problems arise.

Water-seeding Problems

If water seeding is attempted, seeding rate should be in the 90 to 120 lb/ac range, and efforts must be made to discharge the water within 1 or 2 days of planting and to avoid standing puddles of water within the field that can reach high temperatures. Another problem with water seeding comes when a producer seeds into water left standing from the previous crawfish season. Often, remaining crawfish can seriously hamper stand establishment by consuming the rice seed. Successful water seeding, especially during the heat of midsummer, can be difficult even for the most experienced producer with precision leveled fields.

Rotational Cropping Systems

Multicropping of rice and crawfish requires different forage management strategies than monocropping systems. Different crop types are not an option, because crawfish always follows a rice (for grain) crop. (Also see Management Considerations in Chapter 7). Rice variety selection is limited under this production strategy because of the grain production requirements. Rice varieties are generally chosen for their grain-yielding and milling characteristics rather than forage characteristics, which tend to be inconsistent with those traits needed for high density crawfish production. Under moderate densities of crawfish, however, many high grain-yielding rice varieties are sufficient. For maximum benefit under high population densities, rice variety selection in a multi-cropping strategy should also take into consideration the ratooning characteristics of the variety. Residual straw and stalks in harvested rice provide little long-term benefits in terms of food resources. The bulk of the required forage base is derived mainly from ratoon or re-growth of the rice stubble after grain harvest.

Within the confines of best yielding (and milling) rice varieties, consideration should also be given to those varieties with a high propensity for ratoon forage production (Figure 5.8). Commercial rice varieties are constantly changing as new and improved lines are released; therefore, variety selection should be based on the best available information, which is usually obtained from LSU AgCenter extension personnel or publications such as “Rice Varieties and Management Tips” (Pub.2270), published annually by the LSU AgCenter Louisiana Cooperative Extension Service.

Management of the forage crop for crawfish under a rotational strategy is principally related to ensuring proper re-growth from the ratoon crop and minimizing the negative effects on water quality from breakdown of straw and debris from the grain harvest. As with crawfish monocropping systems, fertilization and irrigation is often needed to ensure maximum forage production. Because of previous applications of phosphorus and potassium in the main rice crop, subsequent applications may not be necessary, but often additional applications of nitrogen are required for maximum response and re-growth. Soil tests and/or advice from a professional should aid in determining exact nutrient amendments needed for each situation.

Rice stubble responds best to applications of fertilizer, followed by irrigation, shortly after grain harvest. Extended delays in supplying moisture to the stubble during dry conditions can result in poor re-growth. Also, periodic irrigation or, as with crawfish monocropping, maintaining a shallow flood may be warranted to ensure adequate moisture and uptake of nitrogen applications. Water quality will deteriorate quickly, however, with a constant flood due to high amounts of decomposing plant matter and must be improved before crawfish begin to emerge. Improved quality can be accomplished by water discharge or allowing for complete evaporation, followed by refilling, often several times. Since most rotational cropping occurs in precision-leveled fields, the most efficient means of water and forage management prior to establishment of the permanent flood is to implement a shallow flood (2-4 inches deep) and allow for evaporation, with water replenishment before the soil becomes too dry.

To further minimize water quality concerns, the straw and debris left from grain harvesting operations can be baled and removed, burned or chopped (to speed degradation). Those practices should occur during or immediately following grain harvest and before applying fertilizer and water. Timely rain or irrigation is essential for proper re-growth and also aids in partial decomposition of dead plant material that can cause water quality problems upon flooding for crawfish. Nonetheless, timing of the permanent flood should be delayed in these systems until cool weather persists. This is usually early to mid-October or later in South Louisiana. As with crawfish monocropping systems, weed-free fields are not necessary for adequate crawfish yields, and caution should be exercised anytime pesticide applications are contemplated.

Post-Flood Management of the Forage Crop

Regardless of the production strategy employed or forage type used, few forage management options are available, or needed, following crawfish pond flood-up. For ease of harvesting, some producers choose to establish trapping lanes in the forage crop prior to flood-up. Lanes can be established by mowing, disking or dragging a heavy object in a path where boat “runs.” Other farmers elect to establish lanes, if needed, after flooding by repeated trips with a harvest boat. For best results, trapping lanes should be constructed so that traps rest squarely on the bottom to optimize catch efficiency.

Forage biomass persistence, especially with rice, can sometimes be improved by minimizing flood depths. In general, with the exception of some aquatic plants, the deeper the water depth is maintained in ponds, the more rapidly the forage crop will be depleted. Forages also can become depleted prematurely when crawfish biomass is high or when the crop matures and forms grain prior to winter. Grain formation, aside from coinciding with increased breakdown rates, often attracts birds that, in high numbers, may physically break down the forage crop prematurely.

Rice crops, especially immature stands, may have a tendency to resume growth when temperatures warm sufficiently in the spring, provided living stalks survive the winter and crawfish density is not exceedingly high. This new growth can be critical in providing additional food resources at a time when they are needed the most. To encourage spring re-growth, however, pond managers may need to lower the water level in turbid waters to expose viable nodes on the rice stalk to warmth and sunlight. Lowering water level is an important, but often overlooked, management strategy that increases food resources and can sometimes prevent stunting.

Figure 5.8. In a rotational cropping system, where rice varieties are chosen for their grain production, minor differences may be observed among varieties with regard to forage traits as shown in this experiment. Management practices, however, usually have a much greater influence on forage performance than variety selection.

Chapter 6. Stocking

Crawfish aquaculture relies on natural reproduction of resident or stocked adults to populate the ponds. Yields of harvestable animals within a season depend on broodstock survival, successful reproduction and survival of offspring. In established ponds, however, where production occurs in the same location each year, crawfish populations are usually self-sustaining with no need for supplemental stockings, short of some major catastrophe that interrupts the normal life cycle, such as a major die-off (from pesticides or other contaminates) prior to successful burrowing. Once a pond is established, subsequent crawfish crops rely on holdover broodstock from a previous cycle. This reliance is possible because harvesting operations are inefficient, allowing significant "carry over" of unharvested individuals from year to year, even under the most intensive harvesting efforts.

Since crawfish populations tend to be self-sustaining, stocking is usually only needed in new ponds, when a pond has been idle for a season or longer or after extensive levee renovation or other events that disrupt the reproductive process in permanent ponds. Stocking of new ponds is usually necessary, unless it is known beforehand that sufficient numbers of crawfish of the right species are present to serve as broodstock. When a pond is idle for at least a season and remains dry for much of that time, crawfish broodstock mortality may increase and/or reproductive processes may be hampered to the point that restocking is needed.

Restocking is often needed following major levee renovation because the most productive broodstock are usually burrowed into the levees in open ponds, and earth moving will often destroy broodstock within their burrows or prevent re-emergence in the fall. Sometimes repair or renovation of existing levees is unavoidable, but if done on a large scale during the interval between crawfish burrowing in spring or early summer and reproduction during the fall, restocking will likely be needed. Unfortunately, restocking may not always be possible before the next production season. Severe drought conditions during the critical reproductive period (July to October in the South) also can impair reproduction.

Field rotational methods for crawfish aquaculture do not normally allow for crawfish populations to reach high densities. To ensure adequate numbers of broodstock in a pond that has been out of production for one or more seasons, rotational ponds are usually stocked annually. (Also see Chapter 3.) For the most part, population control is one of the most difficult aspects of crawfish production due to, in part, factors that are not under the producer's control. Many factors associated with stocking practices, however, do fall under the control of a pond manager and can greatly influence production outcomes during the subsequent season. Research has indicated that broodstock survival and reproductive success following stocking can be highly variable, though many of the reasons are still unidentified.

Red swamp crawfish are preferred for aquaculture due to their high fecundity and preference in the marketplace.

Species and Size

Producers in Louisiana should stock only red swamp crawfish because of their high fecundity and preference in the marketplace. In areas with no marketing concerns over white river crawfish, some mixture of reds and whites is acceptable. Size of mature broodstock is of little concern because, although larger crawfish produce a higher number of young, fewer crawfish are purchased per pound of broodstock. Smaller crawfish produce fewer young on average, but more crawfish are purchased per pound. Therefore, total recruitment potential is similar regardless of the size of the broodstock used. Yet, smaller crawfish are sometimes sought because their price per pound is usually lower. Some anecdotal evidence suggests that small, mature broodstock may be hardier than very large adults, but this has yet to be verified.

Dates

New ponds in a monocropping system are usually stocked between April and July when broodstock sources contain a high percentage of sexually mature individuals with at least some advanced ovarian development. (See Chapter 3.) Cost of broodstock is sometimes an important variable when decisions to stock are made, with prices usually lowest near the end of the harvest season. Stocking should follow all major levee work, most notably when levees provide the only exposed ground in a flooded pond. Crop rotational systems that employ the field rotation approach are usually stocked in late May, in June or July, when rice plants are large enough to withstand the crawfish without damage and when most needs for harmful pesticide applications have passed – about 45 days post-planting.

Habitat

Crawfish broodstock are obtained from a variety of habitats (monoculture ponds, rotational ponds and the wild crawfish fishery) and from a wide array of conditions within each of those habitats. Research has not shown a strong link between habitats broodstock may be collected from (say, farmed versus wild) and their survival or reproductive success. It is likely, though, that the environmental conditions within habitats where breeding stock is obtained, such as water temperature, quality and quantity of nutritional resources, crowding and other factors are responsible for much of the variability in reproductive success. Suitable broodstock can be obtained from any type of pond or natural habitat as long as the crawfish are in good health and not under undue stress. Common stressors in any habitat are related to elevated temperatures, low oxygen, poor nutrition and overcrowding, including overcrowding inside traps prior to harvest.

Vegetative cover within the pond being stocked plays an important role in broodstock survival. Although daily nutritional needs are easily met after stocking (because of low densities of crawfish stocked), vegetative cover serves to protect stockers from predators and cannibalism and may serve to buffer the pond temperature. Many types of vegetation also provide access to the surface in times of low oxygen. Vegetation, or some other form of cover, along the water's edge also provides protection from predators while brood crawfish are constructing burrows. If levee surfaces are completely bare and devoid of cover, artificial cover, such as cardboard, plywood, clumps of hay or corrugated roofing material strategically placed along the perimeter near the water's edge will enhance successful burrowing.

Pond water temperature during and after stocking can also be a critical factor. Crawfish cannot tolerate water temperatures over 92 F to 95 F for long periods. Crawfish may seek deep or shaded areas of the pond, if available, to avoid the extreme temperature of midday, but if refuges are unavailable, crawfish will simply leave the pond or die. Increased water depth, vegetative cover and shade, or water exchanges are all options for buffering the effects of high water temperatures at stocking.

Handling

Proper handling of broodstock is also critical for best results. Care should be taken to limit the amount of time broodstock remain in the trap prior to harvest and in storage and transit after harvest. Lengthy exposure to elevated temperatures, direct sunlight or wind will kill or severely stress broodstock, as will rough handling or contamination with foreign substances such as fuel or chemicals (Figure 6.1). Crawfish should be kept clean, moist and at temperatures between 60 F and 80 F. These practices are best accomplished by shading (with tarps, burlap or other suitable materials) and wetting sacks of crawfish periodically. Broodstock should not be kept in refrigerated coolers or completely iced down. Limited use of ice, however, may be a suitable means of controlling temperature and moisture during transport. Harvesting or transporting crawfish broodstock at dawn, dusk or night is also a suitable means of reducing stress. Always exercise caution when handling the animals. Excessive or rough handling can lead to crushing or cracking of the delicate exoskeleton, raising mortality.

Conditions under which crawfish are introduced to the pond are also critical. Contrary to rumor, crawfish should always be emptied directly into the water and not onto dry ground adjacent to the water (Figure 6.2). Because crawfish are mobile, there is no need to equally disperse them over the entire pond or even around the entire perimeter, but some dispersal may be necessary in large fields. However, crawfish should be stocked into each section or segment of a divided pond. Best results are achieved when water temperatures do not differ greatly from the temperature of the crawfish themselves at the time of stocking. Therefore, stocking during the cooler hours of the day/night or during cloudy/rainy weather is one way to minimize this difference and maximize survival.

Figure 6.1. Crawfish intended for pond stocking must be protected from drying out and excessive heat, not to mention contamination with fuel or chemicals.

Figure 6.2. When stocking crawfish, always introduce them directly into the water.

Rates

Stocking rates are based primarily on anecdotal evidence, pertinent factors affecting successful survival and burrowing and, to some extent, personal preference. Recommended stocking rates vary depending on the number of native crawfish present and the amount of cover around and within the pond. Amount and type of cover, such as vegetation in the pond and at the water's edge often will affect the number of crawfish surviving and successfully burrowing after stocking. Stocking rates of 50 lb/ac to 60 lb/ac are recommended for areas lacking native crawfish and with sufficient cover to protect stocked crawfish from predators (both in the pond and while burrowing).

Stocking rates may be decreased from these general recommendations when healthy populations of native crawfish are present. Similarly, they should be increased when conditions make for poor survival following stocking or when burrowing is hazardous due to predators or inclement weather. Although not well documented, it is possible that effective stocking rates may be lowered somewhat when stocking occurs in ponds with permanent levees that already have many old or existing burrows.

In very large ponds with flat bottoms and few interior levees, effective stocking rates may be limited by the amount of linear levee surface around the pond. When the ratio of pond surface area becomes exceedingly large compared to linear levee, available burrowing area at the water's edge may be limited, thereby necessitating lower stocking rates. Simply put, not enough levee is available for crawfish to burrow into.

Anticipated weather patterns after stocking also may influence desired stocking rates. Successful burrowing depends on critical moisture levels in the soil. Drought makes for poor

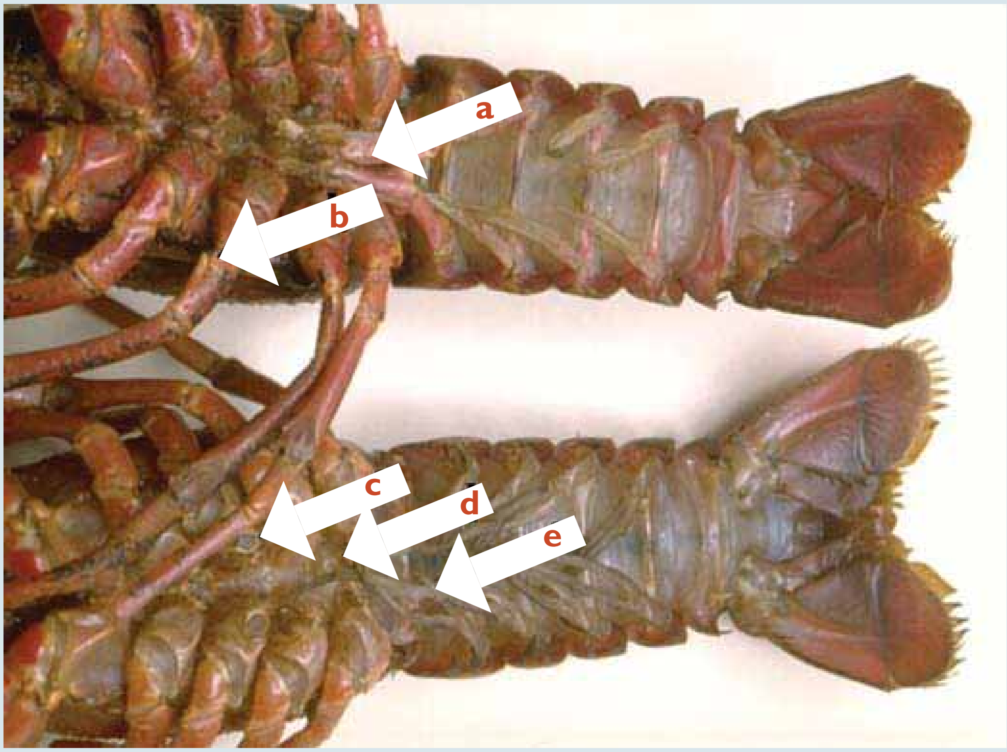


Figure 6.3. The sex of crawfish may be determined by the calcified, modified swimmerets (a) and prominent hooks at the based of the middle two pairs of walking legs (b) in mature males (top), and presence of oviduct openings (c), seminal receptacle (d) and lack of hard, calcified swimmerets (e) on females (bottom), when viewed from the underside.

Conversely, if new ponds have optimal temperatures and oxygen levels, contain sufficient cover to minimize predation and can maintain these conditions for an extended period after stocking, it may be desirable to stock with younger crawfish that are not closely synchronized in their state of maturity. Under favorable conditions, "pre-adult" crawfish can mature and mate in the new pond following stocking, and a mixture of younger and more mature crawfish at stocking might extend the effective spawning period over more months in the subsequent production season. An increased spawning period increases chances of successful reproduction and recruitment under unpredictable conditions before and after flooding, such as drought, hurricanes, delayed flood-up or other events that might interfere with normal recruitment. Nonetheless, for the most predictable results, at least half of the crawfish at stocking should be sexually mature.

In addition, when stocking occurs during summer, at least some portion of the mature females should show signs of ovarian development. Mature females possess yellowish to tan, or even darker eggs (see Figure 2.4 in Chapter 2). The optimal percentages of crawfish with advanced ovarian development and the optimal stages of development at stocking have not been determined and probably vary from situation to situation.

burrowing by lowering water levels and drying out the levees. Frequent rainfall helps stabilize water levels and makes burrowing easier for the crawfish, possibly even allowing burrow excavation away from the water's edge. In short, stocking recommendations of 50 lb/ac to 60 lb/ac are only general recommendations – many producers elect to stock up to 80 lb/ac or more when post-stocking survival is unpredictable. Producers should weigh all of the factors in their given situation and adjust stocking rates accordingly.

Sex Ratio and Condition of Broodstock

The sex ratio and condition of crawfish broodstock both are important. At least 50 percent of the crawfish used as stockers should be females (Figure 6.3). The percentage of females can be higher, but percentage of males should not be higher than females. Healthy males can mate with more than one female. Quality crawfish broodstock also should have an outwardly healthy appearance and be highly active at normal temperatures.

Under typical stocking conditions, most of the broodstock should be sexually mature, especially if environmental conditions in the new ponds are poor (little food or shelter, poor water quality, high temperatures, etc.) or the pond must be drained soon after stocking. If pond conditions or water levels deteriorate soon after stocking, it is desirable that crawfish be able to begin burrowing shortly after introduction. The goal of broodstock management is for crawfish to start burrowing on their own (for reproductive purposes) when they have reached maturity and mated, rather than being forced to burrow for survival purposes because of pond drainage. Therefore, under less than ideal conditions, it is desirable to stock crawfish that are nearly all mature at the time of stocking.

As with any species, reproduction calls for nutritional needs beyond those required for body maintenance or even growth. Crawfish need to have enough stored energy reserves prior to burrowing not only for survival during the long burrow confinement, but also for the reproductive processes that occur in the burrow, where additional food resources are limited or nonexistent. Crawfish used for broodstock should possess adequate nutritional reserves prior to stocking or be able to acquire what is needed following stocking but prior to burrowing. Hence, aside from exhibiting signs of egg development, suitable stocker crawfish also should possess signs of adequate energy reserves in the hepatopancreas (or "fat"), the main energy storage organ (Figure 6.4). The hepatopancreas of dissected crawfish should appear full and fatty and golden or yellow, but not brown, green or watery looking, which indicates poor nutrition and body condition. Examination of a few dissected individuals from each population of crawfish stocked is the preferred way to estimate body condition and reproductive stage.

Preliminary evidence suggest that, in some cases, supplemental feeding of ponds prior to harvesting crawfish for broodstock may improve body condition and increase the reproductive performance of the stockers. Predictable, cost effective feeding protocols, however, have not yet been developed. Furthermore, given an adequate period from stocking to burrowing of several or more weeks in a new pond or rice field, crawfish may be able to gain sufficient energy reserves in the relatively food-rich environment without the use of supplemental feeds.

Figure 6.4. A full, fatty and bright yellow or orange hepatopancreas (digestive gland) inside the body of a mature female prior to burrowing indicates the much needed energy reserves for reproduction (left), whereas a small, watery, amber hepatopancreas indicates a less desirable body condition (right). Note, the dark eggs in the ovary of the crawfish on the left – indicating advanced reproductive development.

Post-stocking Recommendations

To achieve maximum results, stocked crawfish must survive and, if necessary, complete maturity, increase their energy reserves, mate and then burrow successfully. Therefore, environmental conditions in the pond should be maintained to support this process for the maximum number of stockers. This means water temperature and oxygen should remain within acceptable ranges, and water levels should remain relatively constant. Water replacement and/or flushing may be necessary. To provide crawfish every opportunity to burrow successfully and in optimal conditions, water should remain on the field as long as possible, or feasible, after stocking.

Premature draining can prevent some crawfish from reaching the desired state of maturity and/or condition, and also can make burrowing more difficult or impossible. Fluctuating water levels, especially in the absence of timely rains, also can hinder proper burrowing. Unchecked predators, especially fish and birds, can significantly reduce numbers of broodstock, and extensive levee work following burrowing can further reduce survival, reproduction and recruitment. Therefore, attention given to ponds after stocking is as important as other factors relating to the practice of stocking brood crawfish in new or idle ponds.

Summary

To ensure maximum benefits and achieve the most return for dollars spent while minimizing risks, care should be taken to optimize a stocking strategy. Receiving ponds should be completed and readied for animals in advance of stocking with adherence to recommendations for water quality, cover and predator control. All, or in some cases, most of the crawfish to be stocked should be red swamp crawfish, and the stocking rate should be carefully determined based on all applicable factors, including personal experiences for a particular geographical location and habitat. To prevent the proverbial "all the eggs in the same basket" syndrome, consider stocking any given pond on more than one date within an acceptable time frame and with crawfish from more than one source. Furthermore, mixing females with varying maturity/egg stages, depending on when ponds are stocked and the length of time ponds will remain flooded after stocking, will aid in expanding effective spawning dates and lessen potential setbacks from unforeseen circumstances.

Stocking should be done with healthy animals of the proper ratio of females possessing a high level of energy reserves and proper handling during and after harvest. If possible, stocking should accompany rainy weather and/or occur when pond temperatures are the lowest in the day. Pond levels should remain mostly constant, at near normal depths, until a week or so before draining, when water level can be dropped substantially and held at that level until final draining to trigger last-minute burrowing. Ponds should remain flooded for as long as possible or practical following stocking. Lastly, hold levee disturbances during summer to a minimum. The initial stocking of brood crawfish is one of the least costly components of farming crawfish. Any attempt to "save" money by purchasing poor quality broodstock or failure to follow recommended stocking protocols will invariability be very expensive to the producer if reproductive failure is the result.

Stocking Guidelines

- New or idle crawfish ponds should be stocked with approximately 50 to 60 pounds of crawfish per acre.
- Add more if pond (or crawfish) conditions are questionable, and less if crawfish are already present.
- Stock healthy crawfish (sacrificed individuals generally have bright yellow fat).
- Be sure at least 50% are female.
- Be sure at least 50% of females are mature (sacrificed individuals will have yellow to brown eggs).
- Don't be concerned about individual size, or origin of stock, as long as the crawfish are mature and healthy.
- Red swamp crawfish only, from more than one source, is preferred.
- Stocking over several days is preferred.
- Do not use crawfish that were stored in a cooler.
- May to June is the preferred time to stock, although stocking in July may be possible under the proper conditions.
- Move crawfish as fast as possible to the pond; keep wet and shaded.
- Stock all sections of the pond and place crawfish directly in the water, not on dry ground.
- Do not drain fields for at least 2 or 3 weeks after stocking.

Poor water quality that persists for days and weeks is detrimental to crawfish production. Water quality is influenced by many factors, both environmental and biological. Some environmental conditions such as temperature and rainfall are beyond the control of the farmer. Other factors, such as the type of vegetation planted for crawfish in summer, when the vegetation is planted, how the vegetation is managed prior to flooding the ponds and when the pond is flooded will influence water quality in crawfish ponds. Most serious water quality problems occur in the fall, usually in the first two to six weeks after ponds are flooded and later in the early spring when pond water warms. All crawfish farmers will have water quality problems at some point during the production season, but the magnitude and severity is dramatically reduced at the outset by insuring ponds are properly designed, securing a stable and reliable water source, by matching the pumping capacity with production acreage, managing vegetation prior to flooding ponds in the fall and water after flooding and taking corrective management steps when water analysis tests indicate action is necessary.

Water Supply and Quantity Required

Both surface and subsurface water is acceptable for crawfish farming. Wells provide predator-free water, but they have a limited discharge capacity and higher investment and pumping costs. Because well water contains no oxygen and is usually high in soluble iron and toxic hydrogen sulfide, the water must be aerated to add oxygen and remove iron and sulfide prior to entering the pond (Figure 7.1). Surface water is satisfactory if it is pollution-free and if nuisance predatory fish are screened out. Although cheaper to pump, surface water is usually not as reliable in quantity and quality (Figure 7.2).

Pumps, motors and pipes must be matched to obtain the most efficient performance. Lift should be minimized as much as possible to reduce pumping costs. Pond location and local energy costs dictate the type of pump and power source best used for crawfish ponds. Surface water contains predatory fish that should be removed through a 1/2-inch mesh aeration screen (Figure 7.3). Smaller fish passing through the 1/2-inch mesh aeration screen usually don't pose a serious predation problem to young crawfish. These fish are killed when the pond is drained in the summer. If pools or puddles containing fish persist in the pond bottom during the summer, it is important that the puddles be dried or treated with a fish toxicant prior to filling the pond in the fall to prevent contamination of the pond with predatory fish.

Figure 7.2. Surface water is often more economical to use than well water, but its quality and availability vary much more often.

A pumping capacity of 75 to 100 gallons per minute per surface acre is ideal for intensive management strategies for crawfish ponds that average 14 to 18 inches deep when fully flooded. This pumping rate is sufficient to exchange all the water in the pond over four to five days. Complete water exchange may be required in the early fall when water is flooded onto vegetation. Warm weather leads to rapid plant decay and high demand for oxygen. When the water is depleted of oxygen for long periods, significant crawfish mortality or stress that reduces growth can occur. Ponds can be designed to circulate water and maintain satisfactory oxygen levels, thereby reducing pumping and water management cost (see Design and Construction in Chapter 4). Replacing bad water in the pond with

Figure 7.1. Well water, while usually free from contaminants, must be vigorously aerated prior to use.

Figure 7.3. Aeration screens can be designed not only to aerate, but also to reduce the transfer of wild fish into ponds during pumping.

fresh, oxygenated water helps maintain satisfactory water quality. It is more effective to drain a portion of water from the pond and then pump oxygenated water to replace it than it is to drain and pump at the same time. By draining some of the water first and then re-filling, oxygenated water will be distributed through the entire pond. On the other hand, when draining and filling at the same time, many areas of the pond may not be properly flushed of bad water. Exchanging water in crawfish ponds to improve water quality is energy intensive and expensive, and decisions to do so should be based on the results from routine monitoring of water quality, especially oxygen content.

In reality, few crawfish farmers in Louisiana supply 75 to 100 gallons per minute of water per surface acre to crawfish ponds. The following management plan can be used when the water supply is not properly matched to the production acreage. By filling ponds to one-half normal depth at fall flood-up, a pump that supplies 35 to 50 gallons per minute per surface acre will provide sufficient capacity to replace water in several days if required. For example, if the pond is sufficiently level, it can be initially filled to 7 to 9 inches as opposed to 14 to 18 inches. Not only will there be less water to replace during low oxygen episodes, but less vegetation is submerged and oxygen demand is reduced. When temperatures have sufficiently cooled in winter, usually below 65 F, and oxygen demand is reduced, additional water can be added to bring the pond to full depth. One possible disadvantage of the shallow flood is that females with young burrowed near the top of the perimeter levee may not exit the burrow if rainfall in the fall and winter is limited. If the water supply is much less than 30 gallons per minute per surface acre, options for effectively managing water for optimal crawfish production are limited.

Water Requirements

As a general rule, crawfish farmers require a minimum of 2.5 to 4 acre-feet of water per surface acre of pond to initially fill the pond, replace water lost from evaporation and seepage and maintain satisfactory water quality during the 7- to 10-month production season. This amount is equal to adding 30 to 48 inches of water during the production season. Rainfall replaces some of the water loss from evaporation and seepage, but pumping is required to supply the difference.

Water Quality

Water quality depends on management and on properly designed and constructed ponds that have a dependable water supply. Important water quality variables are dissolved oxygen, pH, total hardness, total alkalinity, iron, hydrogen sulfide content, ammonia, nitrite and salinity (salt content).

Dissolved oxygen is the most important and low oxygen may be responsible for the death of more crawfish in ponds, either directly or indirectly, than any other factor. Temperature has a major effect on oxygen levels in ponds (Figure 7.4). Warm water cannot hold as much oxygen as cold water. Also, rising water temperature increases biological activity, so oxygen is consumed at a faster rate. When the water temperature increases from 70 F to 80 F, the rate of oxygen loss caused by decomposition doubles. Potential problems with insufficient oxygen can be expected whenever water temperature exceeds 70 F. During warm periods, ponds with an inadequate pumping capacity and excessive amounts of decaying vegetation will suffer from severe oxygen depletion, which can slow crawfish growth and reduce production if the condition is allowed to persist.

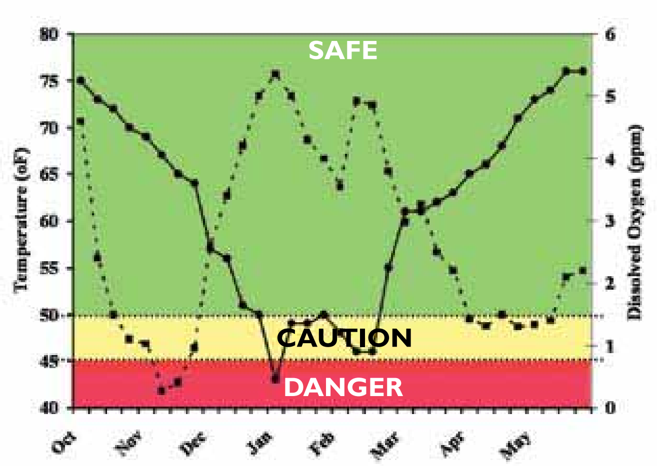


Figure 7.4. A graph illustrating the tendency for oxygen levels to fall as temperatures rise, and vice versa. (Solid line is water temperature and dotted line is oxygen level.)

Crawfish are generally tolerant of low oxygen, but persistent exposure to extremely low oxygen for weeks can reduce production. The first two to six weeks after the initial flood-up is the most critical time for juvenile crawfish. Ideally, dissolved oxygen should be maintained above 2 parts per million (ppm) for good crawfish production but this content can be difficult, if not impossible, to sustain in the warmer months. When oxygen levels remain consistently below 1 ppm throughout the day for several weeks, crawfish become sufficiently stressed that they may cease feeding. Growth will slow and catch may significantly drop until oxygen levels increase. When oxygen levels remain below 0.5 ppm throughout the day for a week or more, newly hatched juveniles and molting crawfish may die. Larger crawfish stressed by low dissolved oxygen climb to the surface on vegetation or traps and expose their gills to higher oxygen levels at the surface (Figure 7.5). This behavior is usually not

Figure 7.5. When oxygen levels become critically low, crawfish attempt to access the water surface, or may even leave the pond.

visually observed with juvenile crawfish because of their small size. The shelf life of live harvested crawfish in the cooler is reduced considerably if they have been exposed to low oxygen in ponds prior to harvest.

Because of high pumping costs, water management decisions should be based on oxygen measurements. No benefit to crawfish health and survival is gained by exchanging water if oxygen levels are satisfactory. Although pond water lacking in oxygen is often clear and dark (the color of tea, coffee or cola) and may have a smell of hydrogen sulfide ("rotten egg" odor), one should not rely on visual observation or smell to determine oxygen concentration. Dissolved oxygen can be checked several different ways. Dissolved oxygen meters are best if you have many ponds to check (Figure 7.6). Most producers, however, choose oxygen test kits because the kits are relatively inexpensive and simple to operate. The easiest kit uses a vacuum ampule that draws in a water sample. The value is determined by matching the color of the sample to a chart.

Monitoring DO

Dissolved oxygen (DO) should be measured regularly, especially during warm weather. Dissolved oxygen levels are lowest early in the morning, so this is when you should check. The first sample should be taken where oxygenated water enters the pond. Take the water sample at a depth half way between the surface of the water and the pond bottom. Also, check at two additional locations in the pond, preferably in one area of good water circulation and one area farthest away from the pump. The general rule is if oxygen levels are 2 ppm or more at dawn, the water quality is satisfactory for crawfish. If levels fall and remain below 1 ppm throughout the day for a week or more, corrective action to add oxygenated water to the pond should be started.

Figure 7.7. The key to good aeration during pumping is to maximize contact between air and water.

Oxygen deficiency is corrected by replacing or exchanging pond water with fresh, oxygenated water or by circulating and aerating existing water in the pond. Mechanical aerators, though not commonly used in the crawfish industry, are effective in aerating water in the vicinity of the aerator but are mostly ineffective in larger ponds with dense stands of vegetation because oxygen can not effectively be distributed throughout the pond. Installation of an aeration tower is recommended to oxygenate well water or surface water prior to it entering the pond. The aeration tower, if constructed properly, also will remove large predatory fish when using surface water. Pumping water through an aeration tower divides the water into small droplets (Figure 7.7). This technique gives maximum oxygen transfer to the water droplets. Properly designed aeration towers will add 1 to 2 pounds of oxygen to the water per horsepower hour. Well water is also aerated to some extent when it is exposed to the atmosphere as the water travels through flume ditches.

Figure 7.6. Oxygen levels should be monitored not only to protect the crawfish crop, but also to avoid expenses associated with unnecessary pumping.

The source water pH after being aerated should range from 6.5 to 8.5, and both total hardness and total alkalinity should range from 50 ppm to 250 ppm as calcium carbonate. As a general rule, most waters and soils used for crawfish production in Louisiana are sufficiently high in hardness and alkalinity and do not require additions of agricultural limestone other than what may be required for the forage crop being cultivated. If the pH, hardness and alkalinity are low, incorporate agricultural limestone into the pond bottom during the next dry cycle. The amount of agricultural limestone required must be determined from a soil test analysis and the kind of forage crop to be grown during the summer. Water and soil samples can be analyzed by the LSU AgCenter's Soil Testing and Plant Analysis Laboratory for a nominal fee, and recommendations will be provided as to the suitability of the water and soil for crawfish production with the results of the analysis. Contact your local LSU AgCenter extension office for instructions on submitting water and soil samples for analysis.

Figure 7.8. Well water often contains iron in the reduced (un-oxidized) form. This problem can be corrected by sufficient aeration.

Dissolved iron and hydrogen sulfide are toxic to crawfish at concentrations often found in well water, but the two compounds are lowered to nonharmful concentrations when the water is oxygenated (Figure 7.8). Where iron and hydrogen sulfide concentrations are high, it may be necessary to place a flume ditch or pond between the well and the crawfish pond to allow the iron to settle out before entering the pond. Non-ionized ammonia and nitrite are toxic to crawfish at concentrations exceeding 2 ppm and 5 ppm (as nitrogen), respectively. Concentrations this high are not likely to occur in crawfish ponds because the crawfish production intensity is low and ammonia is rapidly taken up by aquatic plants present in the pond.

As mentioned in Chapter 5, extreme care must be taken with pesticides in or around crawfish ponds. Only a few agricultural chemicals are labeled for use in crawfish ponds. Crawfish are very sensitive to various classes of pesticides, particularly insecticides, which can be toxic even at low concentrations. Because crawfish are often grown in rotation with other agricultural crops, such as rice, or near agricultural crops where pesticides are used, extreme caution should be taken to insure crawfish are not exposed to pesticides, particularly after the pond or field is flooded and crawfish have already emerged from their burrows. Be sure that your neighbors and aerial applicators are aware that you are farming crawfish nearby. Read and follow label instructions of any chemicals or compounds before using it in or near crawfish ponds. The toxicity of many agricultural pesticides on aquatic organisms, including crawfish, can be found in Southern Regional Aquaculture Center Fact Sheet 4600 "Toxicities of Agricultural Pesticides to Selected Aquatic Organisms," which can be downloaded from the Southern Regional Aquaculture Center Web site. Contact your local LSU AgCenter county extension agent or other knowledgeable professionals when questions about pest problems arise or about the use any pesticides.

Although crawfish are fairly tolerant to salt water, areas subject to saltwater intrusion are not recommended for crawfish production. Tolerance to salinity is directly proportional to crawfish size. Newly hatched young die at 15 parts per thousand (ppt), and juveniles die at 30 ppt if kept in this salinity for a week. Salinity affects crawfish reproduction at much lower concentrations, and the effect of continuous exposure to low salinity on crawfish reproduction is not fully known. Ideally, crawfish ponds should not be located where salinities higher than 3 ppt are likely to occur through most of the crawfish production season. Coastal areas with low salinity water usually have highly organic soils that are not idea for pond construction or for maintaining adequate levels of oxygen throughout the crawfish growing season. The salinity of the source water should be less than 1 ppt if rice or sorghum sudangrass is the desired forage crop. Crawfish farmers in coastal regions should monitor tidal influenced surface waters for salt content particularly during a drought.

Management Considerations

Flooding date is important in water management. Flooding is usually timed to coincide with peak spawning and juvenile recruitment in September and October. For this reason, it is seldom beneficial to flood ponds to full depth before mid-September. If ponds are flooded too early, extreme heat could seriously deplete the water of oxygen, causing significant crawfish mortality if left unmanaged. Several inches of water can be held in ponds planted with rice in early August to suppress weed growth without serious harm to crawfish. Ideally, sustained air temperatures should be in the low to mid-80s in the afternoon and low to mid-60s in the morning before beginning fall flood up, and this is usually early October in southern Louisiana. If ponds are large and pumping capacity is low, or if large amounts of dead plant material are present, delaying flooding until late October or early November when temperatures are lower is usually better. On occasion, heavy rainfall associated with tropical depressions or hurricanes will dump several inches of water on crawfish ponds in late August and early September. Although holding this water to reduce pumping costs is tempting, because of the extreme heat at that time of the year, releasing this water is usually best even if some juvenile crawfish are present. Early rain, however, can usually be safely held at manageable depths on rice forage planted in early August ("green rice").

The type of forage and how the forage is managed prior to flood-up affects water quality. (See monocropping and rotational cropping systems in Chapter 5). Best water quality is maintained in ponds with rice planted in early to mid-August solely as crawfish forage because the oxygen demand of green, actively growing rice is low. Rice-crawfish rotation ponds with large amounts of rice stubble and straw following rice harvest are likely to have serious oxygen problems after fall flood-up unless the straw is baled and removed, burned or chopped and irrigated to speed breakdown and reduce oxygen demand. Significant problems with low dissolved oxygen also can occur in ponds with a dense stand of sorghum-sudangrass because of the high amount of vegetation produced and inability to control other grasses in the pond that have a high oxygen demand. Ponds that are not planted and have large amounts of volunteer grasses usually have severe oxygen depletions soon after flood-up because grasses decompose quickly. Ponds with large amounts of aquatic plants, like alligatorweed, usually have fewer oxygen problems but alligatorweed alone is not a desirable food for crawfish (Figure 7.9).

Crawfish do not have the ability to congregate in high numbers around an oxygen source for short periods of time during low oxygen episodes as do fish. Therefore, aerated water must be transported through the pond to reach all the crawfish to achieve maximum survival, growth and yield. As stated in the Water Supply and Quantity Required section in this chapter, it is important to match pumps and transport systems (pipes, canals or ditches) to maximize energy efficiency and water distribution. Water can be guided through the pond with

Figure 7.9. Natural vegetation such as alligator weed often results in better oxygen levels, but overall lower production.

small internal baffle levees to direct the flow of water throughout most areas of the pond and reduce areas with stagnant or "dead" water unsuitable for crawfish. Ponds can be designed to recirculate and aerate water to maintain water quality using return ditches and re-lift pumps (Figure 7.10). Recirculating water is often less expensive than flushing ponds and has the added benefit of reducing impact of releasing low oxygen water on the environment.

Best Management Practices

In addition to providing a highly valued and desirable seafood product, crawfish ponds serve as favorable wetland habitat to many species of waterfowl, wading birds and furbearers. Often, land that is marginal for traditional row crops is used in crawfish production. Integration of crawfish aquaculture with traditional agricultural land uses serves as a practical means of land and water conservation. Voluntary best management practices (BMPs) are an effective and practical means for conserving water and protecting the environment. Effluent or "tailwater" is discharged when rainfall exceeds pond storage capacity, when ponds are flushed to improve water quality and when drained at the end of the production season. Crawfish effluent water is usually low in nutrients and oxygen demand, but turbidity and suspended solids can be high at certain times of the year. The following set of BMPs have been identified that

Figure 7.10. Re-lift pumps can help circulate and aerate water, reducing the need for water exchanges.

Figure 7.11. Allowing water levels to drop between rainfall events provides the opportunity to capture and use rainwater.

will minimize potential impact of crawfish pond tailwater (effluent) on the environment.

1. Capture and store rainfall to reduce effluent volume and pumping costs (Figure 7.11). Allowing the normal pond level to fall at least 4 inches below the level of the standpipe (or more, depending on the season and pond design) from normal evaporation without re-filling will greatly reduce the volume of water leaving ponds during rainfall events by increasing the storage capacity of the pond to accumulate rainfall. Drain pipes within ponds can be painted a bright color to indicate the target water depth at which pumping is needed. An added benefit of this practice is the reduced need for pumping well water to maintain ponds at or near maximum depths.

2. Install drain outlets to draw overflow from the pond surface. Water from the lower layers of a pond is generally of poorer quality than that near the surface. This difference can be especially true in terms of suspended solids, oxygen demand and nutrients. Pond drains should be constructed to allow water to leave the pond from the surface, not the bottom (Figure 7.12). Existing drains that draw from the pond bottom and

Figure 7.12. During the production season, ponds should drain from the surface, not the bottom, to minimize disturbance of surrounding drainages and watersheds.

incorporate external structures to regulate pond depth should be modified during regularly scheduled pond renovations, to draw water from near the pond surface.

3. Reduce pumping costs and improve flushing efficiency. When flushing crawfish ponds in the fall to improve water quality, avoid pumping and draining at the same time. Fill the pond to one-half to two-thirds of its maximum storage capacity at initial flood-up. To flush the pond, open the drains and allow the entire pond to drop to a depth of roughly one-fourth of storage capacity, then re-fill the pond with fresh water, again to no more than one-half to two-thirds of maximum storage capacity. This type of flushing ensures that stale water will be diluted with fresh water throughout the entire pond, preventing the establishment of "dead" areas where water will not normally flow with conventional flushing. Additionally, less water is used and released to the environment by not flooding the pond to maximum depth with the initial flood-up. The pond can be filled to maximum depth (storage capacity) in late November when temperatures have dropped sufficiently. Alternatively, baffle levees can be used to direct water flow through the pond to eliminate low oxygen areas. In areas where the quality of surface water is occasionally unacceptable or where well water must be pumped from great depths, water recirculation can be a cost-effective alternative.

4. Minimize sediment loading when draining. Harvesting activity, wind and waves and crawfish foraging actions cause turbidity, or muddy water (Figure 7.13). Although this condition can be alleviated somewhat in crawfish-only ponds by postponing draining until most of the crawfish present have burrowed in the early summer, it poses problems in ponds where draining must be accomplished much earlier to allow for a commercial rice or other crop to be planted. In these instances, no specific recommendations have been formulated to reduce suspended sediments in ponds or tailwater, but suspending harvest activities for 1-2 weeks prior to draining may improve water clarity prior to discharge. The use of vegetated filter strips and channel vegetation (vegetated drainage ditches) also will probably be beneficial in improving water clarity because heavy sediments settle out and are trapped as water velocity is reduced as it passes through the vegetation (Figure 7.14). Other approaches, such as maintaining in-pond buffer zones of natural aquatic vegetation like alligatorweed, reduce the level of suspended sediments in water caused by disturbance of the pond bottom from wind and wave action and erosion of pond levees.

Figure 7.13. Weather, harvesting activities and the crawfish themselves all contribute to muddy water in crawfish ponds.

Figure 7.14. While some reduction in flow is unavoidable, allowing drainages to become vegetated with aquatic plants provides an important means of reducing sediment and nutrient losses.

5. Practice water detention during summer drawdown. A majority of suspended solids and nutrients are discharged from crawfish ponds in the remaining 10 percent to 20 percent of the pond water. Retaining water several days prior to complete draining or allowing the remaining water to evaporate if the production practice will allow for this can significantly reduce nutrient loads in tailwater because many nutrients are bound to particles of sediment, which can settle out of the water column prior to discharge (Figure 7.15).

6. Reuse pond water. To save on pumping costs, conserve groundwater and reduce tailwater discharge, if possible; pond water can be pumped into adjacent ponds or reservoirs and then reused. Transfer can usually be accomplished with a low-lift pump, and water can be replaced later by siphon. In some circumstances, it may be possible to drain water directly into ponds with lower elevations.

7. Use tailwater for irrigation. Under some conditions, pond water discharge can be used to irrigate crops. Most crawfish aquaculture in Louisiana occurs in areas used for rice agriculture, and crawfish ponds are frequently adjacent or in close proximity to rice crops. Tailwater discharged in spring and summer into drainage ditches can be re-lifted or, in some

Figure 7.15. Allowing crawfish ponds to sit for several days or weeks prior to final draining can reduce loss of nutrients and soil.

Figure 7.16. Water remaining in crawfish ponds at season's end can be a valuable resource.

Figure 7.17. Drainages that are managed to capture solids as they leave production ponds can often provide a ready source of soil for levee maintenance.

cases, directly used to irrigate and replenish water in rice fields, which are planted in mid-March through April (Figure 7.16). Under some circumstances, diverting pond discharge can result in excessive erosion, so care must be taken when considering this practice.

8. Use natural or constructed wetlands and sedimentation ditches to reduce tailwater solids and nutrients. Natural wetlands are an effective means of treating aquaculture effluents, but care must be taken not to overload these systems. The presence of established stands of aquatic plants in spring and summer in ponds with volunteer vegetation increases nutrient uptake and reduces the level of suspended sediments in water caused by disturbance of the pond bottom from wind and wave action and erosion of pond levees. Although dense stands of volunteer aquatic plants are usually considered problematic in commercial crawfish operations, establishing manageable stands or strips of aquatic plants, such as alligatorweed, inside ponds, even when using cultivated forages such as rice or sorghum-sudangrass, may help to improve effluent quality as well as provide cover and food when other forages have become depleted. Drainage ditches, particularly those with a slight gradient and containing emergent aquatic plants, can effectively function as settling basin for heavier solids. Sediments that accumulate in drainage ditches over time and hinder drainage can be removed in some cases and used to rebuild levees (Figure 7.17).

9. Practice erosion control in drained ponds. When ponds are drained and idle, especially in winter in Louisiana, substantial erosion of the exposed pond bottom can occur, affecting both the serviceability of the pond and the receiving waters on the outside of the drain pipe. For this reason, drains should always be closed if possible when ponds sit empty, and ponds should be partially or completely refilled as quickly as possible.

10. Minimize environmental impacts during pond renovation. Use sediment from within the pond to rebuild levees and fill in low areas (Figure 7.18). Do not remove it from the pond unless absolutely necessary. During renovation, drains should be kept closed to minimize erosion and discharge of sediment. Levee height usually can be increased at this time to allow more management flexibility in capturing and storing rainfall or water from surrounding ponds. In this way, effluents also will be further reduced.

Figure 7.18. Sediments from the pond bottom itself should be the first source of soil for rebuilding levees and filling low areas.

Chapter 8. Harvest

The low-intensity production technology used in farming crawfish requires a harvest method unlike those used to harvest fish. A passive system is used, employing baited traps beginning as early as November and continuing through the following April-June. If fall and winter production of juveniles is low, or where crawfish are grown in northern portions of the state, initiation of harvest seldom begins before March and is often extended into late July.

Crawfish recruitment is continual over much of the 7- to 10-month growing season. Regular, frequent harvests are necessary, in contrast to the infrequent batch harvest with seines common with fish culture operations. Harvesting crawfish with seines or trawls is typically not feasible because of dense vegetation. Crawfish may be harvested with traps from well-managed ponds 40 to 90 days per year. In Louisiana, two-thirds of the crop is generally harvested from March through June, when densities of marketable crawfish are highest and crawfish are most active. Trapping is labor intensive, and over half of all production expenses are associated with harvest. Bait and labor are typically the major harvesting costs. Efficient harvesting is essential for crawfish farming profitability.

Factors Influencing Catch and Harvest Size

Crawfish catch from production ponds can vary two- or three-fold from day to day (Figure 8.1) and is influenced by many factors. Water temperature and density of marketable crawfish are the primary factors that govern seasonal changes in crawfish catch. However, water quality, type and quantity of vegetative forage, weather, lunar phase, as well as crawfish reproduction, growth and molting patterns all play significant roles in the variation observed in daily catch. A summary of the major factors affecting crawfish catch is outlined in Table 8.1.

Size at harvest is largely influenced by environmental conditions – much more so than genetic factors. Crowding reduces growth and usually leads to stunting. Crawfish are aggressive and territorial. Larger crawfish intimidate and out-compete smaller individuals, thereby suppressing growth. To ensure growth of smaller size classes and achieve high yields, crawfish should be harvested soon after attaining acceptable marketable size. Harvesting removes larger individuals from the population, reducing aggression and leaving space and food resources for undersized animals.

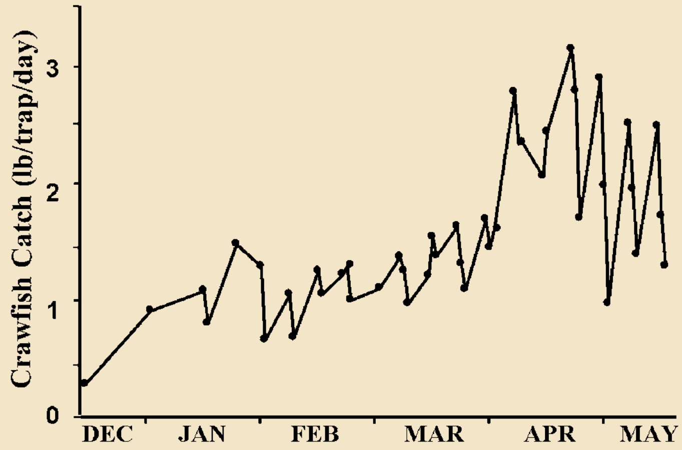


Figure 8.1. An example of seasonal trend in crawfish catch from a Louisiana crawfish pond.

The minimum acceptable size for crawfish for consumption varies with season, abundance and price; however, consumer preference is typically for 23 individuals (“count”) per pound and larger (3 1/2 inches and longer). Large crawfish, 10- to 15-count per pound, usually command premium prices.

Traps

During the early history of crawfish farming, many styles and sizes of traps were used by crawfish farmers, and all caught crawfish with varying degrees of efficiency. Presently, the “pyramid trap,” with three entrance funnels has become the industry standard (Figure 8.2). For years, most traps were made from 3/4-inch mesh, plastic-coated hexagonal-shaped (hex) poultry

Table 8.1. Some factors that influence daily and seasonal crawfish catch.

Factor	Catch Decreases	Catch Increases	Reason
Water temperature	With cooling	With warming	Regulates crawfish feeding activity.
Crawfish density	When sparse	When abundant	Regulates amount of harvestable crawfish.
Relative abundance of vegetation	When abundant	When sparse	Abundance of natural foods and bait attractants not easily dispersed.
Short-Duration Rain Showers and Flowing Water	-	Usually	Aids in bait attractant dispersal and reduced light and stimulates crawfish movement.
Mass molting	Usually	-	Crawfish cease feeding during pre-molt, molt and post-molt phases.
Lunar phase	With full moon	-	Appears to increase the frequency of molting.
Cold fronts	Usually	-	Cooling water decreases feeding activity.
Harvesting intensity	With intense harvesting	With less intense harvest or after a “rest” period	Influences the amount of harvestable crawfish.

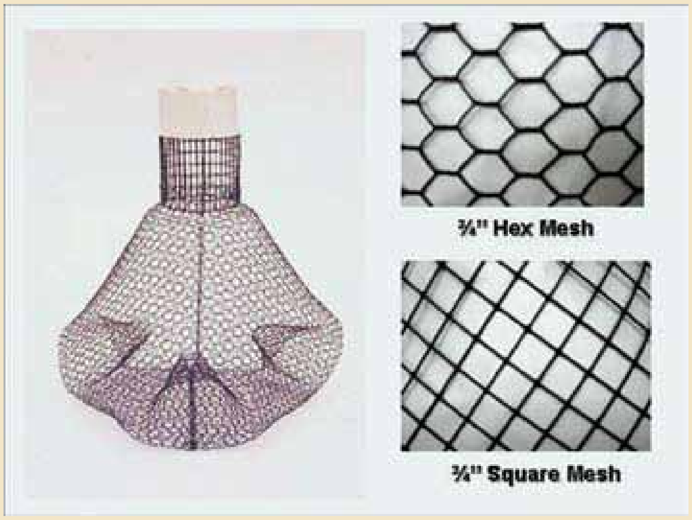


Figure 8.2. Pyramid crawfish trap with optional vertical extension.

wire (19 or 20 gauge). These mesh-sizes typically retained crawfish of minimum marketable size, about 3 inches and longer (35 count per pound). Although hex wire traps dominated the industry prior to 2003, today most traps are made from 3/4-inch or 7/8-inch welded square mesh wire. Traps made of square mesh wire are more durable. Traps made from square mesh wire also retain smaller crawfish than comparable size hex-mesh wire. Research by the LSU AgCenter has shown that 3/4-inch square wire will catch on average about one-third more crawfish than 3/4-inch hex wire traps with an overnight set. The catch with 7/8-inch square mesh traps is roughly equivalent to that of 3/4-inch hex mesh traps.

Pyramid traps are constructed from wire formed into a three-sided, three-dimensional form shaped like a pyramid. Optional cylindrical vertical extensions, usually 6 inches long, are often added to increase the height of the trap for use in deeper water (see Figure 8.2). A 6-inch diameter plastic pipe (or extruded collar) is placed at the top of the trap to function as a handle and prevent crawfish escape through the open top. Traps made from 24-inch wide by 44-inch long to 24-inch wide by 54-inch long wire are the most prevalent sizes. Final overall dimensions of the traps are approximately 17 inches wide at the base and, with a 6-inch extension, about 26 inches tall.

The inside diameter of entrance funnels is usually 1 3/4 to 2 inches. Since wind and wave action and avian predators (herons and egrets) that perch on the plastic collars can cause traps to topple, metal supporting rods (5/16-inch diameter) are often added to minimize toppling. Crawfish traps do not have bait protection containers (bait wells) as is often found in crab traps because catch is usually substantially reduced with their use.

Baits

Bait, which is required to attract crawfish into traps, is the single highest expense in crawfish production and accounts for nearly one-third of production costs. Bait cost depends on the type, amount used per trap, trap density and trapping frequency. Two types of bait commonly used are natural fish baits and formulated baits.

Fish baits are usually sold frozen in 80-pound or 100-pound boxes. Clupeid or "sardine-like" fishes, specifically gizzard shad and Gulf menhaden or "pogy" (Figure 8.3) are the most widely used natural baits in Louisiana where commercial fisheries exist for both species. Common carp, buffalofish,

Figure 8.3. Commonly used crawfish baits: (top) gizzard shad; (middle) menhaden or "pogy"; and (bottom) manufactured baits.

herring ("slicker"), suckers and catfish are also used. Shad, menhaden and carp are superior to other natural fish baits as attractants. Beef pancreas ("beef melt") commonly used by recreational trappers, is an effective attractant but too expensive for commercial use. When a shortage of bait occurs in the Louisiana bait fisheries, significant quantities are shipped in from other states.

Formulated crawfish baits, often referred to as "artificial" or "manufactured" baits, were commercialized in the early 1980s and are produced by several feed companies, both within and outside of Louisiana. These cylindrical pellets consist mainly of cereal grains, grain by-products, commercial flavoring agents and a binder. They are generally one-half to 2 inches in diameter and 1 1/2 to 3 inches long and sold in 50-pound bags.

Fish baits are seasonal in supply and price and more expensive than formulated baits. Large farms may have freezers or coolers for storage, but smaller farms require daily deliveries. Labor is needed to cut the fish to puncture the swimbladder so it will sink and to portion it into efficient sizes, which further adds to its cost. Formulated baits do not require refrigeration and are easier to handle. Some companies offer different formulations for use in cool or warm water.

Baiting Strategies

Significant cost reductions can be achieved by employing efficient baiting strategies. The main considerations are selection of bait type relative to season and quantity of bait used per trap. Shad and menhaden are more effective attractants than formulated baits at water temperatures below 70 F (Figure 8.4), and, in Louisiana, fish baits are used almost exclusively during winter and early spring trapping (November through March). Even though fish baits are more expensive, the average two- to three-fold increase in catch over formulated baits under these conditions compensates for the additional bait cost. When water temperature exceeds 70 F to 75 F and ponds become depleted in forage (corresponding to late March to early April in South Louisiana), formulated baits become equally effective or more effective than fish baits, and they are the most cost-effective

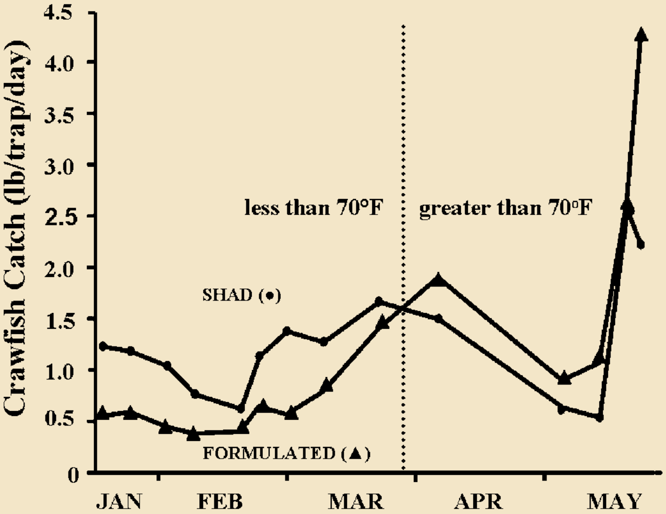


Figure 8.4. Example of the effect of water temperature on attractability of shad (●) and a formulated bait (▲).

attractants. At water temperatures of 65 F to 75 F, a combination of fish and formulated bait added to traps in approximately equal portions can increase catch as much as one-third over fish alone or formulated bait alone; however, the logistical inconvenience of handling two baits at the same time in harvesting boats must be considered when employing this strategy.

During winter, when crawfish feeding activity is minimal and the number of harvestable crawfish is still relatively low, studies suggest that one-fourth pound of bait per trap is sufficient to harvest available crawfish. When waters warm in the spring and the crop of harvestable crawfish nears maximum levels, the quantity of bait should be increased to about one-third pound per trap. Although it is not practical to portion bait into each trap carefully, farmers can gauge and monitor bait use by keeping good records on the total quantity used for the number of traps in a pond or the farming operation. For example, when using one-third pound of bait per trap per day, a 100-pound box of fish bait should be sufficient to bait 300 traps. If only 200 traps are baited, too much bait is being used. A 50-pound bag of formulated bait is sufficient to bait 150 traps. The trapper should pay attention to the amount of bait remaining in the trap after a 24- or 48-hour soak (set time). If significant bait residue remains in the trap the amount can be reduced somewhat. If bait is rapidly consumed, however, consideration can be given to increasing the amount of bait. Fresh bait should be used each trapping day, especially with fish baits. To maximize crawfish movement to freshly baited traps, bait residue should not be disposed of in the pond.

Trapping Strategies

Traps are placed in rows to facilitate harvesting by boat (Figure 8.5). Distance between traps depends on trap density (Table 8.2) and a spacing of 40 to 60 feet between individual traps and between rows is most common. Where annual yields of harvestable crawfish are expected to exceed 1,000 pounds per acre, a trap density of 18 to 22 square-mesh pyramid traps per acre, baited and emptied three to four days per week is recommended. It is not uncommon for farmers to use a lower trap density of 10 to 15 per acre if a low-standing crop of crawfish is present or if large areas are to be trapped and labor is limited. Trap density should be increased by two to three traps per acre if hex-mesh pyramid traps are used. If buyers require daily delivery of crawfish, or the price is high and catch justifies the effort, crawfish can be harvested five to six days per week,

Table 8.2. Spacing between rows (in feet) and the distance between traps (in feet) to obtain a specified number of traps per acre.

Distance Between Traps	Distance Between Rows	Traps Per Acre
40	40	27
40	50	22
40	60	18
40	72	15
50	40	22
50	50	17
50	60	15
60	40	18
60	50	15
60	60	12
66	66	10

Figure 8.5. Spacing of pyramid traps in a commercial crawfish pond.

but the average size of crawfish and catch per trap will usually decrease after a few days. If multiple ponds are present on the farming operation, harvesting activities can be rotated among production ponds.

Normally, traps are emptied 24 or 48 hours after baiting. The 48-hour soak time is generally employed in late fall and winter when crawfish activity is slow and standing crop of harvestable crawfish is low. Typically, it is best to harvest three or four consecutive days per week with several days rest between trapping episodes when crawfish are abundant and active.

Following nonharvest days, unbaited traps need not be lifted from the water and emptied prior to baiting because no additional yield is obtained by removing these crawfish (often referred to as "walk-ins") prior to baiting. To some extent the average size of crawfish caught is correlated with the time traps remain in the water. The shorter the trap set, the higher the number of small crawfish caught. After the bait has been consumed, or the attractants in the bait have dissipated, some crawfish are able to escape through the entrance funnels, and escape is easier for the smaller animals. After several days of intense trapping, the average size of crawfish decreases and the catch often declines as larger animals are removed and the standing crop of market-size crawfish decreases.

Insufficient harvesting in ponds with dense crops of crawfish hastens forage depletion and increases aggression among animals, resulting in growth suppression and stunting. Ultimately, yields and profitability can be greatly reduced. Conversely, excessive trapping may reduce harvest size by removing crawfish before they have had sufficient time to grow to larger sizes, and harvest efficiency is decreased in this way. Because of the basic inefficiency in current trapping methods and gear, there is no evidence to indicate crawfish can be over-harvested. The more farmers monitor and understand the structure of their populations, the better equipped they can be to make decisions regarding harvest intensity.

Crawfish Harvest Recommendations at a Glance

- Three-funnel pyramid trap, 3/4-inch or 7/8-inch square wire
- 18-22 traps/acre in high-density ponds, (typically permanent monocropping ponds)
- 10-15 traps/acre in low-density ponds, (typically rice-crawfish field rotations)
- Trap 3-4 days/week
- 24-hr or 48-hr trap soak time
- 40-90 trapping days per season
- Use fish baits below 70°F, formulated baits above 70°F

Occasionally, harvesting schedules and strategies must be adjusted to accommodate markets. Buyers may prefer to have the product delivered only on certain days, such as Thursday through Sunday, when demand is usually highest. Additionally, market demand for crawfish early in the season may allow for various sizes of crawfish to be sold with little problem, but when supplies are more abundant, trapping strategies may need to be adjusted to maximize crawfish sizes, even at the expense of overall yield. As markets evolve and conditions change, maximizing profits in crawfish production no longer automatically means maximizing yields. Planning and good communication with potential buyers early in the season can allow trapping strategies to be developed that respond to market preferences and improve a producer's competitive position.

Harvesting Machinery

Methods used to empty traps vary within the industry. Producers with ponds less than a few acres in size rarely use motorized boats because of the added expense. Traps may be emptied by harvesters who walk shallow-water ponds while pulling or pushing a small boat. One person can empty about 400 traps per day. Other trappers use small, flat-bottom boats propelled by push-pole or paddle, but this method is no more efficient than walking.

In larger ponds, a boat propelled with an engine and drive mechanism adapted for use in shallow water is the most efficient harvesting equipment. One approach used widely in the crawfish industry is the Go-Devil® or similar designs, with 8- to 18-hp air-cooled engines or larger and long shafts with weedless propellers (Figure 8.6). The boats have flat bottoms, are made from aluminum and are typically 14 to 16 feet long by 4 to 6 feet wide. It is common for

Figure 8.6. Crawfish harvesting boat powered by Go-Devil® propulsion unit.

Figure 8.7. Crawfish harvesting boat powered by rear-mounted hydraulic wheel.

these boats to travel down trap lanes with fishermen emptying and re-baiting each trap from one side of the boat without stopping. The first trap is lifted, dumped and re-baited in the time it takes to reach the next trap. The freshly baited trap is set beside the next trap, and the process continues throughout the pond. A boat powered in this manner generally requires two persons, one to empty and re-bait the traps, and a second to steer. As many as 300 traps per hour can be emptied and re-baited.

Many crawfish producers prefer to use a rig designed specifically for harvesting crawfish (Figure 8.7). This boat uses a 12- to 24-hp air-cooled engine that operates a hydraulic pump and motor to propel a metal wheel attached to the boat. Metal cleats are welded to the wheel, which is mounted either to the front to pull the boat forward, or to the rear to push the boat in shallow water. The wheel's hydraulic steering can be operated with foot pedals, leaving the driver's hands free to empty and re-bait traps. A single person can handle about 150 to 200 traps per hour. Up to 300 traps per hour can be emptied and baited with two persons. Rigs with the hydraulic wheels mounted in the rear are preferred whenever boats must cross levees, either within or between ponds. Some hydraulic-propelled boats are also equipped with side-mounted rubber wheels to allow travel down farm roads for short distances.

Boats are equipped with sacking tables to consolidate harvested crawfish. Trap contents are emptied onto the sacking table, which usually has two to six loose mesh "vegetable" sacks temporarily attached. Each sack can hold 35-45 pounds of crawfish depending on how tightly the harvester packs them before changing sacks. Bait residue and other debris remain on the table to be discarded while crawfish drop into the hanging sacks. Producers are increasingly using in-boat graders to cull submarketable animals while still in the pond (Figure 8.8). Larger crawfish remain on the grader and are sacked. Smaller crawfish are usually returned to the pond but this may not be advisable in many situations (see Managing Harvest, Chapter 9).

Figure 8.8. Typical shop-built "in-boat" grader designed to allow submarketable crawfish to be returned to the pond immediately after harvest via a chute placed below the parallel bars.

Pond Flood-up

Crawfish are confined to the burrow until the hard plug that seals the burrow is sufficiently softened by external moisture. (See Chapter 2). Pond flooding, especially when associated with heavy rainfall, facilitates and encourages the emergence of crawfish from burrows. Brood females emerge with young (and sometimes eggs) attached to the abdomen, and hatchlings are quickly separated from the females to become independent. Because reproduction is somewhat synchronized in pond-reared crawfish, ponds are routinely flooded in autumn to coincide with the main period of recruitment. Continuous recruitment and differential growth often results in a population of mixed sizes, especially in monocropping situations (Figure 9.1). Typically, spawning in burrows, hatching (either in burrows or ponds) and emergence of females from burrows all take place more or less continuously from September through November. As a result, sufficient young-of-the-year crawfish are usually available throughout this time period to produce the season's crop.

Figure 9.1. Many established crawfish ponds contain a wide range of size classes most of the season.

Timing of fall flooding is particularly critical in crawfish farming. The goal is to time flooding to provide the best habitat for young-of-the-year recruitment, and the most fundamental factor relating to the timing of flooding involves water temperature. Warmer water is more conducive to faster growth of crawfish. The warmer water is, however, the less oxygen it can hold. At the same time, the warmer the water is in a newly flooded field, the more rapidly oxygen will be consumed in the breakdown of vegetation. Unless extremely high amounts of water are available for daily exchanges, early flooding almost always results in depressed oxygen levels. This situation is aggravated if most of the vegetation is already dead or begins breaking down rapidly upon flooding. This occurrence can significantly reduce survival and growth of any early emerging crawfish and reduces profitability through increased pumping costs and reduced yields (because of poor utilization of forage and reduced crawfish recruitment). Therefore, timing of pond flood-up should reconcile water quality issues with optimal crawfish growth opportunities associated with warm weather.

Flooding also must be timed to coincide with the development of the forage crop, whether it be rice, sorghum-sudangrass or volunteer vegetation. If terrestrial vegetation is flooded too early, growth may be curtailed, and the breakdown process may be accelerated. In cooler waters, even poor quality forage will persist longer, and the slower breakdown process generally results in more nutrition for the crawfish crop.

It is important to remember that ponds need not be fully flooded during the 1- to 2-month period when brood crawfish and their young emerge from their burrows. In some situations, young-of-the-year crawfish can successfully begin growing in as little as 4 to 6 inches of water, especially if abundant green vegetation provides cover. During the period following initial flooding, maintaining good water quality and high oxygen levels is more important than filling the pond to its full depth.

Population Management

Despite some efforts to limit farmed crawfish populations only to the red swamp crawfish, excluding the white river crawfish from ponds whenever possible, both species are responsive to routine culture practices and often coexist in production ponds. In general, these two species have environmental requirements that are conducive to the low input aquaculture systems used in Louisiana and surrounding states, and they are frequently found in the same water body. Though the abundance of one species may vary among and within culture ponds from year to year, red swamp crawfish most often dominate and are the desired species in the marketplace. It has been hypothesized that the abundance of red swamp crawfish is linked to their greater reproductive potential because growth and survival do not differ greatly between the two species. Other factors also may be involved. In some cases, white river crawfish increase in abundance as the culture pond ages and can become the dominant species over time.

It also has been speculated that ponds flooded in November, rather than in September or October (in Louisiana), may favor the white river species because later flooding dates better coincide with the timing of reproduction for that species. Research has shown that the species of crawfish that enters the pond first in greatest numbers after fall flood-up has the best likelihood of dominating the population. Thus, if red swamp crawfish become established first after the pond is flooded, they will dominate the population and later harvest. If juvenile white river crawfish become established before red swamp crawfish juveniles enter the population, white river crawfish will dominate the population and subsequent catch.

Currently, no reliable management recommendation is made for ridding a pond of white river crawfish once they have become established. If the problem with white river crawfish is so severe that it interferes with a farmer's ability to market the catch, a few management options can been considered, but it must emphasized these recommendations are not known to be reliable nor have they met with predictable success. They include (1) draining a pond quickly in March or April before white river crawfish mature and burrow in large numbers, followed by re-stocking the pond with red crawfish; (2) flooding a pond in September to allow red swamp crawfish hatchlings to emerge before white crawfish. Extra caution must be taken to manage water quality associated with September flooding; (3) if the crawfish farming operation is large enough, taking a pond out of production for 1 or 2 years to kill most of the resident crawfish, followed by restocking with red swamp crawfish can be tried.

Figure 9.2. While there is no mathematical relationship to predict overall yield based on the number of small crawfish in dip net samples, this type of monitoring can provide an indication of population density.

Management of a crawfish population after flood-up is complicated by the inability of producers to assess the population accurately. Because of continual recruitment and difficulties in sampling, crawfish producers have little knowledge of the density and structure of the crawfish population in their ponds. Sampling is crude and accomplished by dip net sweeps and baited traps (Figure 9.2). Population management entails little more than controlling timing of the flood to coincide with normal reproduction peaks, ensuring adequate water quality and food resources and adequate harvesting pressure to remove market size animals. Reducing densities to control overpopulation in ponds has shown promise in limited research but has not yet become a common practice. Supplemental stocking in underpopulated ponds within a production season sometimes occurs but may not always be feasible.

Supplemental Feeding

As described in the forage section of this manual (Chapter 5), crawfish production in the southern United States relies almost solely on established forage crops for providing nourishment to growing crawfish. Feeding of prepared feeds is not a common practice as it is in shrimp farming or most fish farming enterprises. Rather, crawfish receive their sustenance from sources within a complex food web, similar to that which occurs in natural habitats. The natural food chain, at times, may be inadequate to sustain maximum crawfish production, especially when forages become depleted or when adequate forage crops are not established. It is also likely that, as crawfish density increases beyond some optimum density, natural food resources become depleted. Under these conditions, production of highly nutritious invertebrates, important components of the crawfish's diet, may be lacking, resulting in poor crawfish growth or, worse, stunting at submarketable sizes.

Feeding or supplementing natural food resources has been tried by some producers to increase crawfish production. Farmers have provided hay in place of, or in addition to, growing vegetation. Hay has been added either at the beginning of the season prior to flood-up or later in the season after the depletion of standing vegetation. Large round bales or numerous smaller square bales have been placed in ponds, often marginally distributed within the ponds, with bales either left intact or broken up to some degree. Conventional thinking at the time was that hay would undergo decomposition similar to forage crops to furnish the needed "fuel" for the food chain. Positive results, in terms of more or larger crawfish harvested, were usually nondetectable and often the practice resulted in deterioration of water quality.

Lack of (or poor) results from hay supplements was due to the fact that the hay did not function as plant fragments from standing forage crops would. First, the distribution of hay, even if bales were well dispersed in the pond, usually only covered a small fraction of the entire surface area of the pond. This restriction was not conducive to maximum benefit because crawfish, and their prey, are well scattered throughout the pond and commonly do not congregate to feed. Second, decomposing plant material is most nutritious for a relatively short period (days to weeks, depending on water temperature), so anything less than regular offerings of fresh hay, well-dispersed over the entire pond area, does not meet the nutritional needs of the organisms in a pond over the course of a season. Furthermore, large amounts of decomposing hay are wasted because it cannot be fully utilized by the target organisms and can lead to oxygen depletion, either locally surrounding the bale or over the entire pond.

Various agricultural byproducts, such as manures, sweet potato and sugarcane products have been evaluated as supplemental feeds for crawfish production, but most have provided no noticeable or only marginal results and are considered nonpractical. The problems arise more from practical aspects of handling, frequency requirements of feeding and distribution over the pond, rather than strictly nutritional limitations.

Feeding of formulated, pelleted feeds, much like those used in catfish culture, have been tried in a number of commercial and experimental crawfish ponds over the years. Positive results were inconsistent and difficult to measure, and feeding practices frequently proved uneconomical even when a positive biological response was observed. Although some carefully controlled studies showed a positive response of crawfish to supplemental feed additions, results were variable and unpredictable. Some studies reported no increase in average yield or harvest size after feeding. Others reported significant increases in yield; however, yield increases were mostly from an increase in the harvests of smaller, low-valued crawfish.

Supplemental feeding studies under simulated pond conditions in outdoor tanks or in a laboratory setting with high densities of crawfish consistently demonstrated the limitations of forage-based culture systems and usually yielded more, or larger, crawfish. Yet, repeatedly, responses from supplemental feeding in ponds were marginal and unpredictable at best and proved disadvantageous at times. It was found that feeding while harvesting could actually result in lower yields – possibly because of satiation of crawfish appetites or interference with the attractant from the bait in traps, resulting in lower catches. Feeding immediately after the last day of harvest each week, when using

Broodstock Feeding

One objective that may justify the use of supplemental feeds in crawfish culture, short of increasing overall yield or harvest size, is to increase body condition and energy reserves of broodstock. Recent research, although limited and preliminary, has indicated that crawfish survival and reporduction within the burrow during summer/fall may be better in females with the greatest energy reserves. Feeding practices may be better applied toward animals to be used for broodstock, rather than for growing crawfish for harvest.

an intermittent harvesting schedule of three to four consecutive days per week followed by a three- or four-day reprieve from harvesting lessened the chance of reduced yields when feeding but did not always eliminate it. (Also see Managing Harvest below).

In short, there are probably times when the food chain associated with a forage crop is limited and nutritional supplementation may be needed to sustain maximum production. Aside from concerns with feeding and harvesting, however, other constraints that currently limit the economic use of supplemental feeds include knowing when feed is needed, how much to feed, how often to feed, specifically what nutrients are limited and when feeding will predictably produce positive results. If most of the crawfish population has reached or is nearing sexual maturity (even at a small size), further growth is limited, even with ample food. Therefore, much of the benefits of supplemental feeding will not be realized. Furthermore, it is difficult to obtain an accurate assessment of crawfish populations, and, based on research, it has been determined that supplemental feeds offered to highly overcrowded crawfish populations may be only marginally effective at increasing average size or yield. Therefore, without the ability to accurately assess situations in a pond and counter with cost-effective feeding practices that will yield positive results on a consistent and predictable basis, no dependable recommendations exist for use of supplemental feeds in forage-based crawfish ponds.

Feeding expensive feeds, formulated to meet all the nutritional requirements of the cultured animal (as in catfish production), may not be the most cost-effective means of supplementing the nutritional needs of crawfish. Since forage-based systems inherently furnish much of the required nutrition for growing crawfish, low-cost, incomplete feeds used as true supplements to the natural food web may provide the most cost-effective alternative. Because of the intermittent feeding nature of crawfish and the presence of other invertebrates, much of the dispensed feed will cycle through the food web to be utilized indirectly by crawfish. Therefore, supplemental feeding must be viewed as "feeding the total system" and not just the crawfish. Based on what is known about crawfish ponds, it is likely that protein and/or energy are the primary limiting factors when natural foods become scarce. Therefore, single feedstuffs high in energy or protein may provide adequate nutritional supplementation at a fraction of the cost of expensive, formulated "complete" feeds containing vitamins, minerals and other expensive nutrients.

Certain agricultural grains and seeds may be appropriate supplemental feeds for crawfish raised in ponds containing some natural foods. Agricultural seed crops are usually high in protein and/or energy, are routinely available in crawfish farming regions, are easy to apply and are usually a fraction of the cost of high protein formulated feeds. Damaged (broken) or low-grade products are often available at reduced prices. Rice grains and whole soybeans, among other grains, have been investigated as supplements to crawfish with encouraging results in highly controlled conditions. When repeatedly evaluated under realistic field conditions, however, similar problems existed with harvesting, timing, assessments and predictability, as with the use of pelleted feeds. Nonetheless, research is continuing to investigate strategies whereby supplemental feeds might be used to effectively augment the forage-based system and increase economic returns in a more reliable manner. As of yet, no feeding recommendation is available for increasing production or average harvest size in forage-based systems on a predictable and feasible basis.

Some research has been directed at the use of feeds in "off-season" or "year-round" nonforage-based crawfish ponds. Under that scenario, feeds are intended to furnish nearly all of the nutritional needs of growing crawfish – much like intensified catfish operations. Although experimental results were encouraging, no large commercial operation has yet employed this type of production system. Moreover, because of the increased cost of producing crawfish in such a system, the breakeven price is increased dramatically, making it more suitable for crawfish culture outside of Louisiana near prime out-of-state markets.

Although in high-density permanent monocropping ponds low reproduction efficiency may be offset by large numbers of crawfish, this balance is usually not the case in new or rotational ponds requiring stocking. Since a limited number of brood crawfish are initially stocked in first year ponds, reproductive condition is important. Crawfish broodstock are often obtained from densely populated ponds and at a time when food availability is at its lowest, so improvement in reproductive condition through short-term feeding prior to capture of broodstock may improve survival and reproductive success after stocking, especially if new ponds will be drained soon after crawfish are stocked. Little research has been completed with regard to this objective for feeding, but an active research program is underway to determine the merits of such short-term feeding practices and to establish some possible guidelines.

Managing for Larger Crawfish

Factors affecting crawfish size

Developments in the Louisiana crawfish industry and its major market outlets over the last 15 years have led to an increased interest and economic incentive for production of larger crawfish. Until about the late 1980s farm-gate pricing was influenced largely by supply and demand with little regard to crawfish size as long as it was above the minimum acceptable size of about 30-count crawfish to the pound. Therefore, the principal emphasis of management for crawfish producers was to maximize total production of harvestable crawfish. A number of factors, however, combined to result in the development of price differentials according to crawfish size. These included a small, short-lived export market (demanding only the largest crawfish), development of mechanical grading practices and an increased reliance on live markets as Louisiana's processing industry was undercut by cheap imports of crawfish meat from the People's Republic of China during the 1990s.

Price differentials favor the larger crawfish (Figure 9.3); however, there are currently no industry standards as with

Figure 9.3. Most wholesale and retail markets pay higher prices for larger crawfish. Occasionally, when supplies are abundant, having large crawfish to sell can guarantee access to markets that would otherwise reject smaller crawfish.

the shrimp industry and many other seafoods. The number of grades and grade category classifications vary depending on geographic region and time of the year, as well as among individual wholesalers and distributors. Aside from price differentials, producers of small crawfish are further constrained because of the lack of opportunity for selling smaller crawfish at certain times of the year at any reasonable price. With the loss of much of Louisiana's processing industry during the 1990s, opportunities for salvaging the catch of smaller crawfish at those times when consumer demand is only for the largest animals have been greatly reduced.

Small crawfish are often associated with higher overall yield potential. If the percentage of small crawfish in the catch becomes great enough, however, buyers will often refuse delivery, leaving producers with few viable options. Also, in times of oversupply, those producers with the largest crawfish are most able to sell their product. Currently, excess production of small, low-value crawfish is a major industry problem and can be economically devastating to individual producers. Therefore, the principal focus of managers is now on maximizing yields of larger crawfish and/or on increased production within the early season when demand exceeds supply.

Although not thoroughly characterized, some of the factors influencing crawfish growth or size-at-harvest are thought to include harvesting strategy, certain water conditions, food quality and quantity, population density, genetic influences or combinations of these factors. Little information exists of direct genetic influences on crawfish growth or size-at-maturity, and most data indicate that environmental factors are far more important than genetic effects.

The first form of grading, or size selection for harvested crawfish, is the wire-mesh trap. As indicated in Chapter 8, the industry has largely moved to the 3/4-inch square mesh trap, which retains smaller crawfish. Harvest intensity also can affect the size of crawfish in the catch. Intense trapping efforts (with high trap density and/or frequent harvests) usually increase overall yields, but can decrease the average size by temporarily decreasing the density of larger crawfish and removing some crawfish before they have sufficient time to grow to larger sizes. Insufficient harvesting can foster overpopulation, which in turn hastens forage depletion and contributes to the stunting of crawfish at sub-desirable sizes. Trap-soak (set) time also can affect the size of crawfish in the catch, because small crawfish are more effective at exiting the trap. Longer trap soak times generally yield larger crawfish.

The most obvious effect on crawfish harvest size relating to water conditions is water temperature. At temperatures below about 60 F, growth slows considerably and, while trap catch efficiency is also reduced, smaller crawfish size is usually the result of concerted harvesting efforts at the lower temperatures. Chronic low oxygen concentrations also can suppress crawfish growth, and rising water temperatures and highly fluctuating water levels are thought to encourage growth to slow or stop in conjunction with maturation, even at smaller sizes.

It was once thought that the overwhelming factor causing the excessive production of small or stunted crawfish in production ponds was food deficiency. Harvests of stunted populations are nearly always associated with premature depletion of the forage resource. It is likely that as crawfish density increases beyond some optimum level, food resources are depleted and nutritional shortages limit growth. Research has shown, however, that crawfish grown at more than about 15 per square yard will have a slow growth rate and small size at maturity even with supplemental feeding of high-quality feeds. It has been clearly demonstrated that crawfish exhibit density-dependent growth. Final size appears to be inversely related to density, and high feeding rates with high quality diets are unable to counteract the effects of density on crawfish growth. Research suggests that the overwhelming factor affecting size-at-harvest in commercial crawfish ponds is not simply food shortages, as was once thought, but principally overcrowding.

Managing density

Few sound management strategies exist for the predictable production of large crawfish in commercial ponds, mainly because stock replenishment depends on natural recruitment, which is affected by many variables outside of the control of pond managers. High population density has been identified as the single most limiting factor affecting crawfish growth and harvest size, yet control of crawfish numbers is possibly one of the most elusive aspects of crawfish pond management.

The density of young-of-the-year crawfish in ponds is influenced by many factors but is basically a function of the number and size of successfully spawning broodstock and the survival of their young. Overpopulation is most likely to occur in permanent monocropping ponds after several annual production cycles and is least likely in newly established ponds or in ponds previously out of production for some time. Therefore, rotating production into different fields, as is commonly used in some rice/crawfish rotational practices, or allowing a permanent pond to remain drained for one or more complete cycles can be a management technique for preventing overpopulation when production resumes. For producers with limited land, however, suspension of production in ponds for an entire season could lead to loss of revenue that might outweigh the benefits of population control.

If overcrowding is expected, delaying the permanent flood to December or later, well after the peak spawning period, might be a suitable method of preventing stunting in ponds because delaying would likely reduce the number of recruitment classes, although this method has not been well documented. It also could delay the bulk of crawfish production, which is usually accompanied with lower prices. Caution must be emphasized with this approach because if cool weather prevails late into spring and/or ponds become deficient of food resources, many late recruits may not have time to attain large harvest size before ponds are drained in summer.

When permanent monocropping ponds are overcrowded, another possible technique to reduce recruitment the following season is to drain the ponds earlier than normal, before too many crawfish become sexually mature and begin mating, and to drain them rapidly, thereby stranding many crawfish before they have sufficient opportunity to burrow (Figure 9.4). This

Figure 9.4. Draining ponds early and/or rapidly can sometimes reduce overpopulation problems the following season by stranding some of the adult crawfish present before they have a chance to burrow.

method may not always be effective, particularly in older ponds where established burrows are plentiful and mature broodstock are available at all times. If sufficient broodstock mature and burrow before the drain and reproductive success is high, this technique will fail to achieve the desired result. Early drains also can cause a significant loss of income since harvesting ceases prematurely.

Since most mature broodstock establish burrows in exposed surfaces of the pond, namely the levees, farmers have an additional opportunity to reduce population density for the subsequent season. After the ponds are drained for the summer, they could conduct maintenance or renovation on a substantial portion of the levees. Such activities can significantly reduce crawfish reproduction and/or recruitment. Although not a very precise method, major disturbance of burrow entrances can reduce the survival, reproduction or emergence of the occupants.

If the right proportion of linear levee, especially the interior area of the levee, is reworked with heavy equipment between seasons, overpopulation may be corrected or reduced from one season to the next. If too many burrows are compromised in this manner, however, overcorrection is possible and yields and profits suffer. Because of the many variables associated with reproduction and recruitment success, and the typical non-uniform burrow patterns in the levees, general management recommendations cannot be provided for this imprecise method of population control. It is recommended however, that at least some percentage of the levee area remain undisturbed during the critical burrowing period to provide an opportunity for some reproduction and recruitment to occur normally.

All of the previously mentioned methods for correcting overpopulation are based on preventative measures, taken to prevent recurrence in a subsequent season. Since the cause of overpopulation is highly variable and largely dependent on environmental factors beyond the manager's control, preventive measures are frequently ineffective, or to the contrary, over-compensatory, and loss of production (and income) is a possibility. Practices required to readily identify overcrowding and corrective actions that yield predictable results within a production season are lacking. Some research, however, has been focused on this approach with mixed results.

Pond sampling, beginning six to eight weeks after flood-up, is important in determining population density and potential for overcrowding. Although accurate sampling protocols are lacking for crawfish aquaculture, an experienced manager should be able to ascertain relative density estimates with a combination of sampling gear such as dip nets and baited traps (both small and large mesh traps) and visiting the pond at night with a light around the edges. If overcrowding is anticipated, actions taken to reduce crawfish densities within a current production season should probably occur after peak recruitment, which occurs from October to December, but before ponds warm in the spring. Density reductions before peak recruitment occurs may not be adequate if large numbers of subsequent recruits appear. Reductions too late in the spring may accompany food shortages and reduced opportunity for maximum growth.

Research and anecdotal evidence has indicated that when overcrowding was determined, temporary and partial pond draining in February or early March in South Louisiana was sometimes sufficiently effective in reducing crawfish density to result in larger crawfish after refilling. Ponds were drained, except for puddles and ditches amounting to about 10 percent to 30 percent of pond bottom areas, for two to seven days and then refilled. Density reduction occurred as a result of concentrating the crawfish in a limited area where they were more exposed to the hazards of predation and cannibalism.

In theory, although not verified, more deaths should occur in the younger age classes with this method – and this would be the preferred outcome. It should be clearly noted, however, that mixed results have been obtained with this risky approach. In some cases, crawfish reductions were insufficient to affect a positive response after refilling, and in other cases over-reductions occurred, resulting in larger crawfish but also in a substantial reduction in yield. Because of the unpredictability of this method and various circumstances that could affect outcomes, no management recommendations have yet been devised. The success of midseason draining to reduce overcrowding and produce subsequent harvests of larger crawfish depends first on accurate assessment of population density and then appropriate density reduction at the appropriate time – a difficult task with any measure of predictability.

Other possible means of reducing density within a season, including intensive harvesting with both small-mesh and commercial traps, have been investigated without success. Because of the inefficiency of current harvest methods, it is unlikely that sufficient reduction in density can occur using only baited traps.

Managing food resources

Although population density appears to be the single most important factor determining crawfish growth and size-at-harvest in typical production ponds, limited food resources also can be a significant contributing factor. Moreover, high crawfish density can significantly increase the rate of depletion of the forage in ponds, creating food shortages that act to exacerbate density's effect on harvest size. To date, supplemental feeding has had little impact on increasing size-at-harvest in ponds; however, its use at various densities and under varied conditions has not been thoroughly investigated. A well-managed forage-based system seems to be an appropriate feed delivery strategy and remains the best way to ensure the most cost-effective transfer of nutrients to growing crawfish when population density is within the optimum range.

Certain management considerations are necessary to ensure maximum use of food resources from forage-based production. Probably the single most desirable aspect in any vegetated system is the ability of the forage to continually and consistently furnish adequate amounts of material to the food chain for the duration of the production season. As detailed in Chapter 5, research has shown that plant type (and variety) and plant maturity status have major effects on persistence and re-growth potential. The ability to achieve adequate re-growth, as a function of variety selection, planting date, standing density of crawfish and, if necessary, water management have been directly linked with increased production of larger crawfish late in the harvest season – where it is often the most beneficial. Mixtures of plant types that bring complimentary benefits in terms of food value and vertical structure, especially late in the season, also may yield positive results related to increasing average crawfish size at harvest.

Research is continuing to investigate management approaches to improve forage-based systems and their application in crawfish production. Also, with a better understanding of crawfish population dynamics, feeding habits and nutritional needs, a cost-effective supplemental feeding program eventually may be devised to aid producers in achieving larger crawfish.

Managing harvest

Modification of the typical harvesting routine also has shown some potential to increase crawfish size-at-harvest. Intense trapping five to six days per week can reduce harvest size by removing some animals from the population before they could otherwise grow to a more desirable market size. A three- or four-day per week harvest approach, as discussed in Chapter 8 usually can increase efficiency of harvest as well as overall crawfish size. Intermittent or rotational harvest schedules also have been shown to increase the proportion of large crawfish in the catch. When an entire pond or portions of a pond are harvested on an intermittent basis, crawfish have an opportunity to undergo additional molt(s), thus increasing crawfish size and value between trapping episodes. Various periods of trapping/nontrapping, as well as use of supplemental feeds during the nontrapping period, have been investigated, although additions of pelleted feeds in a limited number of studies did little to increase yield or size-at-harvest. Generally, in controlled studies, short term (two to four weeks) intermittent trapping has increased crawfish harvest size but at the expense of total yield, probably from decreased trapping frequency – that is, fewer trap-sets per season.

The usefulness of an intermittent harvest schedule depends on many factors, such as population density and size structure, food availability, time of year, trap density and marketing conditions. It should be clearly noted, however, that under some conditions of pond culture, notably overcrowding, food shortages or when a majority of crawfish are nearing or have reached their maturity molt, harvesting reprieves are not effective at increasing crawfish size. LSU AgCenter researchers, as well as individual producers, are continuing to explore different trapping strategies and trap designs for their effectiveness with regard to producing larger crawfish.

Another option that is currently used to reduce small crawfish offered for sale is the use of "hand grading" or "in-boat graders" (see Chapter 8). Some low-volume producers may hand cull subdesirable crawfish, while many producers currently use a device that consists of parallel bars attached to an in-boat sacking table. Various bar spacings are used, but the intent is for sub-desirable size crawfish to fall through a platform of parallel bars mounted in the bottom of the sacking table when crawfish are emptied onto the table from the trap. Crawfish that fall through the bars are usually funneled back into the pond, while crawfish that are retained above the bars are moved into sacks for sale.

A common misconception with this approach is that the smaller crawfish returned to the pond will be harvested later at a larger, more valuable size. Though in some cases this may be true for a small percentage of animals, many crawfish will never be recaptured because of natural or predator-related mortality and the inefficient nature of trap harvesting. In many cases, reharvested crawfish will be caught later at reduced prices. Moreover, returning crawfish to a pond that is overcrowded and/or deficient in food resources may exacerbate those problems, resulting in a reduction of average crawfish size in subsequent harvests. In many cases, it may be better, and more profitable, to sell the smaller crawfish, even at a much reduced price, than to return them to the same pond. Alternatively, submarketable crawfish may be deposited in a pond that is known not to be overcrowded, with the intentions of harvesting later, a practice known as "relaying," although the economic advantage of this practice is not always certain and should be scrutinized carefully.

Relaying to increase crawfish size

The presence of small, stunted crawfish in the catch usually occurs near the end of the production season (late April-June in Louisiana), which normally coincides with the period of lowest prices. By that time, forage resources often have been depleted, crawfish have reached maturity and further growth is unlikely. On some occasions it has been possible to achieve further growth from severely stunted populations by transferring, or relaying, crawfish from their original surroundings in poor environments to improved environments. Although this practice has been rarely used, research has demonstrated its potential for increasing crawfish size, thus their value and marketability. Suitable conditions exist on many farms for use of this practice, not only to increase market value of crawfish but to extend the harvest season and increase net returns from already-integrated agriculture operations. Because many farmers co-culture crawfish and rice in rotational systems and because these cropping seasons overlap, it is common to have newly established rice fields at a time when crawfish stunting normally occurs in forage-depleted crawfish ponds. Overlapping seasons provides the opportunity of using the rice production acreage as a valuable resource for obtaining additional growth and increasing the market value of crawfish. Research has shown that, with careful management, acceptable rice yields can be obtained following harvest of relayed crawfish, and potential net farm income could be substantially increased by intercropping crawfish in a rice crop in this manner. It should be noted, though, that some rice yield will invariably be sacrificed because of crawfish harvesting activities, primarily through plant destruction associated with trapping lanes. Extreme caution should also be exercised regarding pesticide use in the rice crop.

This intercropping approach may be particularly suitable to rotational culture systems where crawfish culture follows the rice crop. In lieu of the normal practice of stocking broodstock, this practice calls for stocking of stunted animals at much higher densities in the young rice crop. Following several weeks of growth, most of the larger, higher-value crawfish would be reharvested prior to rice maturity, and any remaining animals would suffice as broodstock for the subsequent crawfish season. Stocking rates of up to 1,000 lb/ac have been investigated, but it should be noted that, although individual crawfish weight more than doubled, retrieval rates were lowest for the higher stocking rates, and the overall harvest recovery rate was equal to the amount of crawfish stocked.

The economical feasibility of relaying or any other management practice intended to increase the production of large crawfish in a commercial operation depends on a price structure to the producer that favors larger crawfish. The magnitude of the price differential for large crawfish will determine the economic benefit of management practices that focus on anything other than optimum yields of medium-size animals. Market demands and price differences should always be taken into account when implementing or recommending costly management practices.

Diseases

Serious disease problems associated with nonintensive crawfish culture are thought to be rare. Individual crawfish are known to be susceptible to various pathogens, such as bacteria, virus, fungi, protozoans and parasites; however, epidemic outbreaks sufficient to affect commercial production in earthen ponds have not been demonstrated. Significant disease problems are more likely to be encountered in intensive, high-density holding systems, such as purging and soft-shell production facilities. One study reported that of 15 outbreaks of bacterial septicemia (*Vibrio mimicus* and *V. cholera*) diagnosed in Louisiana crawfish, four cases were from ponds and 11 were from high-density holding systems. Diseases are most likely to occur during periods of elevated temperatures and/or periods of oxygen stress.

All North American crawfish are suspected vectors of the *Aphanomyces* fungi, or plaque fungus, that was notorious for eliminating many populations of native European crawfish in numerous lakes, rivers and streams. Although carriers, North American crawfish, including those cultured in the South, are not normally affected by the fungus. Procambarid crawfishes are sometimes affected by other agents that do not necessarily have an effect on production but may hinder crawfish marketability because of certain physical effects. Microsporida can infest the abdominal muscle, giving it an unattractive milky-white appearance (porcelain disease), and various ectocommensal organisms that attach to the exoskeleton can limit the acceptability of crawfish if the infestation is heavy. These conditions are not usually common and have little economic impact, although at times buyers may refuse to accept lots of crawfish with heavily soiled exoskeletons.

Because of the insignificance of known diseases in pond culture of crawfish, disease management is not deliberate. Practices that prevent food shortages, overcrowding and low oxygen (common stressors) are the extent of practices related to disease management in the crawfish industry.

Predators

Crawfish are, however, susceptible to any number of predators that thrive in and about the shallow, vegetated waters of crawfish ponds. Predaceous aquatic insects consume young, recently molted crawfish. Bullfrogs, amphiumas (a large eel-like salamander) and several species of water snakes flourish in crawfish ponds and readily consume all sizes of crawfish (Figure 9.5). Various turtles and the occasional alligator will prey on crawfish. Small mammals, such as the Norway rat, mink, raccoon, opossum and otter are often abundant and will consume crawfish and sometimes the bait placed in crawfish traps. Raccoons and otters also will damage traps when getting to the crawfish and/or bait. Although collectively these predators can consume large quantities of crawfish, crawfish reproduction and growth rates are usually sufficient to prevent major harvest losses.

Figure 9.5. Apart from humans, many wildlife species have a taste for crawfish.

Even though predatory fish, if not controlled, can be the most significant predator encountered in crawfish ponds, avian predators, especially carnivorous wading birds, are perceived by many producers to cause the most harm. Fish are easily controlled, though often difficult to eliminate from ponds if they become established (Figure 9.6). Fish are controlled by thoroughly drying pond bottoms during the interval between

Figure 9.6. Wild fish, such as these green sunfish, can cause large losses of young-of-the-year crawfish. Unless ponds can be completely dried each summer, these fish can be very difficult to eradicate.

seasons or by treating standing pools of water with a fish toxicant, followed by proper screening of incoming water. Some fish manage to enter ponds by swimming up drain structures or on the feet, feathers or fur of other animals visiting the ponds. If not controlled, fish will consume large quantities of crawfish and/or compete with crawfish for the natural food items that crawfish rely on.

Avian predators are not as easy to control as fish. Many bird species consume crawfish, and, except for allowable hunting seasons for certain waterfowl, nearly all piscivorous (fish-eating) birds are federally protected (Figure 9.7). Although the actual impact on operational costs and production is not known, many producers perceive bird depredation as a significant and growing problem. Carnivorous waterbirds find crawfish ponds to be food-rich havens, and these ponds often offer water and food resources when they are in short supply in natural habitats. Some researchers have provided convincing evidence of a direct relationship between the increase in colonial wading bird numbers from the 1960s to 1980s and the increase in crawfish pond acreage in Louisiana during that period. Anecdotal evidence also suggests that some noncrawfish-eating species have recently adapted their feeding habits to take advantage of the plentiful supply of crawfish from aquaculture ponds. Effective control measures are lacking, and the size and shape of most commercial crawfish ponds prevent the economical use of netting or other exclosures.

Figure 9.7. Many crawfish producers perceive bird predation to be a serious problem, but their actual impact on production and profits is not well documented.

Nuisance Wildlife

Note: These recommendations are in accordance with Louisiana Revised Statutes (RS) at the time of publication. Always check with your local wildlife authorities (Enforcement Division, Louisiana Department of Wildlife and Fisheries, USDA Wildlife Services, US Fish and Wildlife Service) for the most up-to-date rules and regulations prior to undertaking animal control activities.

From time to time, nuisance wildlife species invade crawfish ponds and in some cases cause serious damage. You can do some things but not others to take care of the problem, depending on the species.

Raccoons and otters are the most frustrating pests since they turn over traps and sometimes mash, mangle and twist the wire so badly that the trap is destroyed. Mink may swim to a few traps, consume some crawfish, and steal cut fish, but this problem is usually limited. Nutria and muskrats will dig holes in levees, costing the producer both in time repairing levees and in pumping costs to replace water (Figure 9.8). Beavers can cause problems by blocking drain pipes. These nuisance animals are classified as "fur bearers" and are protected or regulated by certain wildlife laws. During trapping season these animals may be trapped by a licensed trapper, skinned and the hides sold [RS56:259 C. (1)]. In certain other situations, farmers and landowners may trap or shoot these animals when they are a nuisance. The technicalities are different for each species, however.

Figure 9.8. If left uncontrolled, burrowing rodents can cause costly damage to crawfish ponds, occasionally resulting in levee failures.

Farmers and landowners can hunt raccoons and opossums with a .22 caliber rifle anytime during the year when they are found destroying crops [RS56:116.1 C.(2)(a)]. Raccoons also can be hunted by licensed hunters at night with at least one dog and using one .22 caliber rifle [RS56:116.1 C.(1)]. There is no bag limit during the trapping season, but the limit is one per night after trapping season [RS 56:116.1 C. (3)]. The law also allows raccoons and opossums to be taken by licensed hunters during rabbit season [RS 56:116.1 C. (4)].

Landowners, or their designees with written permission, can use live traps for raccoons, otters, mink and muskrats and relocate the animals to suitable habitat without a permit. If live traps cannot be used, a licensed trapper can catch and dispatch these animals during trapping season. Outside of trapping season, a special Nuisance Wildlife Permit can be obtained from the district offices of the Louisiana Department of Wildlife and Fisheries (LDWF) or USDA Wildlife Services, to trap or shoot these animals when causing problems. USDA Wildlife Services offices are located in Crowley (337-783-0182), Port Allen (225-389-0229) and Monroe (318-343-6499).

Nutria and beaver are considered nuisances and can be taken by trapping or shooting by a farmer or landowner without a license, except during trapping season when a trapping license is required. They can be shot only during the day (sunrise to sunset) [RS56:259 E]. Under Title 76 (Section 125) of the Louisiana Administrative code, a landowner or his designee with written permission, can trap or shoot nutria and beaver (and opossums, coyote, skunks and armadillos) during daylight hours anytime during the year when causing a nuisance. Muskrats are not included in these laws. Muskrats must be trapped during trapping season by a licensed trapper.

Poisons generally are not recommended for controlling any of these fur-bearer species. Directly poisoning nontarget species (pets and other wildlife) and secondary poisoning of animals eating on the carcasses of the dead animals are likely dangers. The only exception is the use of zinc phosphide for controlling nutria. This gray powder is a restricted-use pesticide (a private applicator's license is required to purchase this chemical) and is available from USDA Wildlife Services. Animals should be pre-baited to feeding sites for several days with carrots or sweet potatoes before applying the zinc phosphide to the bait.

The only other approved use of poison is for Norway rats and field rats. These are a nuisance around the boat and bait-cutting station, and can harbor serious and even deadly diseases. Weather resistant blocks of rat poison need to be placed in bait boxes or deep in holes or places where rats hide. The poison should not be broadcast in the open. Reducing hiding places by burning bait boxes and keeping the area clean also helps to control rats.

Birds are sometimes a problem when they feed on crawfish or turn over traps. In ponds with high numbers of crawfish, egrets and herons may not hurt the crop at all. In ponds with few crawfish, every crawfish is valuable. Egrets and herons along with ibis and seagulls are protected by federal laws and can only be harassed to leave the field. Pop guns used for blackbirds do not typically work with these birds. Pyrotechnics (fireworks) are the best thing to use to discourage these birds, but persistence is the key. Scaring the birds once a week won't do any good.

Cormorants often tip over traps in an effort to get to the crawfish or eat the fish bait. In areas where cormorants are plentiful, scare tactics are not effective without some lethal control. Federal regulations make it legal for lethal control of double-crested cormorants at "commercial freshwater aquaculture" facilities in 13 states, including Louisiana, when it is determined that cormorants are damaging an aquaculture crop. Although no special federal permit is required steps must be taken to insure compliance with federal law. First, USDA Wildlife Service personnel must confirm that damage is being done by double-crested cormorants to crawfish, and the producer must show evidence that he/she has used other established non-lethal options to minimize damage by cormorants. The USDA Wildlife Service can then issue to the producer Form 37 which allows for the lethal take of double-crested cormorants. The producer must meet the requirements of the federal depredation order, and these include the following: (1) Records (log) of the kill must be kept that include date, number killed and location. The producer must also report any accidental take of other cormorant species. Records must be kept for 3 years and a copy provided annually to the United States Fish and Wildlife Service. (2) Cormorants can be taken only within the boundary of the crawfish farming facility during daylight hours using firearms, and shotguns must use steel shot. (3) Cormorants must be disposed of by donation, burial or incineration. They cannot be traded or sold. (4) No lethal control of double-crested cormorants can be taken within 1,500 feet of nesting wood stork colonies, within 1,000 feet of wood stork roosts, within 750 feet of feeding wood storks and more than 750 feet from bald eagle nest.

A trap with only crawfish heads left in it is probably the result of turtle predation. Turtles will circle the trap and pinch off the crawfish tails that poke out through the trap wire. Turtles can be trapped using a wire "box" with an open top and sides sloping inward that allows the turtles to climb in but not out.

Fish predators can eat a significant amount of crawfish, especially in the fall when young crawfish leave their mothers. Bullhead catfish (pollywogs) and green sunfish ("bream") are the worst culprits and are difficult to remove from the pond once they invade.

Control Methods

Raccoons

1. Find a licensed trapper to catch the animals during trapping season.
2. Buy a trapping license and trap during the trapping season.
3. Hunt raccoons with a .22 caliber rifle during daylight hours if the animals are causing crop damage.
4. Hunt raccoons at night with a dog and .22 caliber rifle. No limit during trapping season. A hunting license is required.
5. Obtain a Nuisance Wildlife Permit from LDWF or USDA Wildlife Services to shoot during daylight hours or trap the raccoons.

A good trap for catching raccoons is a leg grabber trap called Lil Griz Get'rz, baited with liquorish candy or marshmallows. Leg-hold and body-grip traps are effective but are more tricky to set.

Otters

1. Find a licensed trapper to catch the animals during trapping season.
2. Buy a trapping license and trap during the trapping season.
3. You don't need a permit to live trap and relocate otters. Live trapping otters is not practical, though.
4. Obtain a Nuisance Wildlife Permit from LDWF or USDA Wildlife Services to shoot during daylight hours or trap the otters.

The best trap for otters is the 8-inch or 10-inch body gripping trap such as the Conibear 220 or Duke 280. This trap should be set in a run where the otter is crossing a levee or rigged in a bucket as a curiosity set. Otters are extremely difficult to trap with standard leg hold traps or box type traps.

Muskrats

1. Find a licensed trapper to catch the animals for you during trapping season.
2. Buy a trapping license and trap during the trapping season.
3. Obtain a Nuisance Wildlife Permit from LDWF or USDA Wildlife Services to shoot during daylight hours or trap the muskrat.

The best muskrat trap is the 4.5-inch body gripping trap (Conibear 110) set by holes in the levee. Baiting with a piece of sweet potato sometimes helps.

Nutria and beavers (also coyotes, armadillos, skunks and opossums)

No permit is necessary to trap or shoot during daylight hours when they are causing problems. Nutria can be trapped using leg hold traps set on levees where the animals are crossing. Body gripping traps will also work on nutria. Snares are easy devices to set to catch beavers where they enter the water. The large body-gripping traps (10-inch Conibear or Duke) also work well on beavers.

Norway rats

1. Limit problems by keeping boats and bait storage areas clean.
2. Weather resistant poison baits are effective if used in bait boxes or other hidden areas to avoid nontarget species.

Birds (herons, egrets, ibis, sea gulls, pelicans, etc.)

Pyrotechnics and other scare tactics are the only approved means to drive away these pests.

Double-crested cormorants

When cormorants are damaging freshwater aquaculture operations, and scare tactics are ineffective, shooting is allowed with approval by USDA Wildlife Services and compliance with certain stipulations as listed above.

Summary

Technical advice on animal damage control is available from the USDA Wildlife Services, Louisiana Department of Wildlife and Fisheries and the LSU AgCenter. No state or federal agency, however, will send personnel to take care of this problem for a producer. Producers are required to follow all state and federal laws governing the control of these nuisance wildlife species.

Developing Your Business

Attention to details during the planning and operations will increase your chances of business success in crawfish production. As with any enterprise, it is often best to start small, learning and growing into an economically viable farming enterprise. When considering a crawfish farming business for the first time, consider these factors, requirements and the following questions:

- Do you have a realistic business plan developed with monthly objectives and projected cash flows for the first year and annually for each of the next three to five years?
- Do you have access to capital for start-up, operation or expansion? Are your cost estimates and pricing projections reasonable? Do you have adequate cash reserves for equipment failure and other unforeseen problems?
- Will a lender accommodate your production/marketing cycle?
- Have you identified your primary and alternative markets?
- Are the estimated profits worth your labor and resources? Is the profit potential for crawfish farming competitive with other possible investments or activities?
- Are you willing to work long hard hours, daily, during the harvest season?

The economic analysis of crawfish production has evolved as the crawfish industry has grown in technology, sales and complexity. Production cost estimates and knowledge about markets are essential. Abundance of wild crawfish has a depressing effect on prices when wild and farm-raised supplies overlap. A crawfish farmer must be aware of varying market conditions and how the market changes will affect the profitability of the operation. A key to success is the understanding and estimation of production costs. Precise investment requirements, production and harvesting costs are not available for every farming situation. Projected costs and breakeven prices for various crawfish cropping systems are developed annually by the LSU AgCenter's Department of Agricultural Economics and Agribusiness and be accessed from the LSU AgCenter's Web site.

A record-keeping system is needed to generate financial reports and production records. The basic purposes of records are reporting, control, evaluation and planning, but good records can be an important resource when dealing with government crop programs or litigation. Financial reports that give the manager vital information about the business are the most important function in record-keeping. Through financial statements, a manager can determine profits (or losses), the feasibility of the business plan, the accumulation of net worth in the business and the profitability of each part of the business. Financial reports consist of income statements, balance sheets, cash-flow statements and enterprise reports.

A good records system allows the manager to see what is going on in the business, decide what is working and what is simply costing too much. A good example in crawfish farming involves multiple fields within an operation and the decision process to allocate harvesting and pumping resources. Evaluation during the year is critical to keeping costs as low as possible while increasing income. Producers often don't know how much has been spent in total or by item (bait, fuel, supplies, etc.) and therefore cannot stop wasteful practices. Financial planning for the coming year is needed to decide if sufficient net income will be generated to meet business goals. As prices paid and received change, the ability to pay bills on time and service debt can change. A projected cash flow will show the feasibility of the proposed business plan.

Production records and reports contain information about the technology used in production. It's important to maintain records of pumping time, traps used, bait (type and amount), water quality information, crawfish production time (hours, labor), results of grading and sales income per acre and per day. Careful analysis will identify the strengths and weaknesses of the production process. Future management decisions concerning forage, water, population dynamics, harvesting strategies and marketing are easier and more accurate if good records are kept. Correction of problem areas results in increased production efficiency. Also, when a crop is lost because of a natural disaster or pollution, records are needed to prove losses.

Records can be kept either in handwritten ledgers or by computer. Either method takes about the same amount of time to record information. The LSU AgCenter's Cooperative Extension Service has several publications that can be used to form a basis for your own system. These include the "Louisiana Farm Record Book" and the "Louisiana Farm Inventory Book." Computer technology allows reports to be prepared much more easily and quickly. Computer record systems should be given careful consideration when choosing a record-keeping strategy. More experienced computer users may prefer to use spreadsheet programs rather than prepackaged business management software. Contact your local parish office of the LSU AgCenter Extension Service office for more information about financial planning for farming operations.

Records of maintenance, repairs and hours of operation should be kept for all equipment.

Chapter 10. Markets and Marketing

Whether from aquaculture or the natural fishery, the supply of live crawfish is highly seasonal, with peak of the harvest occurring from March through June (Figure 10.1). Historically, most of the domestic supply has been consumed in Louisiana and surrounding southern states, particularly Texas, the Mississippi Gulf coast and the Florida panhandle (Figure 10.2). Because of restricted geographical areas of production, seasonal supply, unstable prices and cultural mores, crawfish sales nationally have been limited, but have increased in recent years.

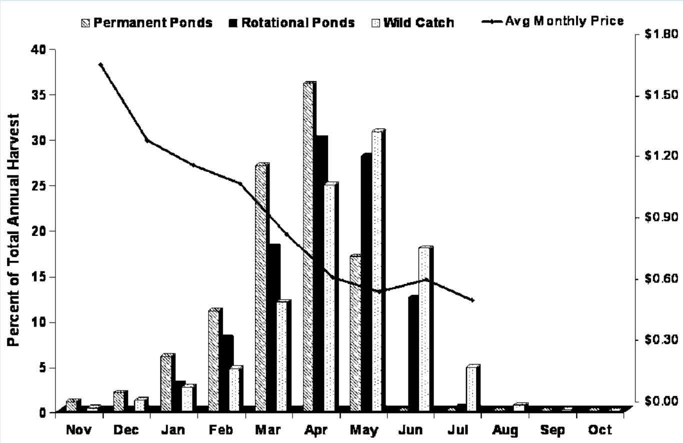


Figure 10.1. Distribution of annual Louisiana crawfish harvest from aquaculture and the commercial wild fishery from the Atchafalaya River basin. Percentages depict a 10+ year average. Average monthly price is the 5-year average (2000 through 2005) for pond-raised crawfish in southern Louisiana.

Figure 10.2. Major regions of live crawfish sales, usually within a day's drive of southern Louisiana. Markets for live crawfish and tail meat continue to grow in other areas of the United States. Stars represent major metropolitan cities for crawfish sales including, but not limited to, New Orleans, Baton Rouge, Shreveport, Houston, Dallas, Biloxi, Mobile, Pensacola and Atlanta.

Product Forms

Live crawfish

All crawfish are marketed live by farmers, and live crawfish comprise most of the final sales to consumers. Producers of large crawfish have a competitive advantage, especially when the supply of live crawfish exceeds demand. In times of oversupply, generally the larger crawfish remain in the live market and smaller crawfish are processed for meat. Most producers sell live crawfish to a primary wholesaler (Figure 10.3) or a processor, although a limited volume is sold directly to retail

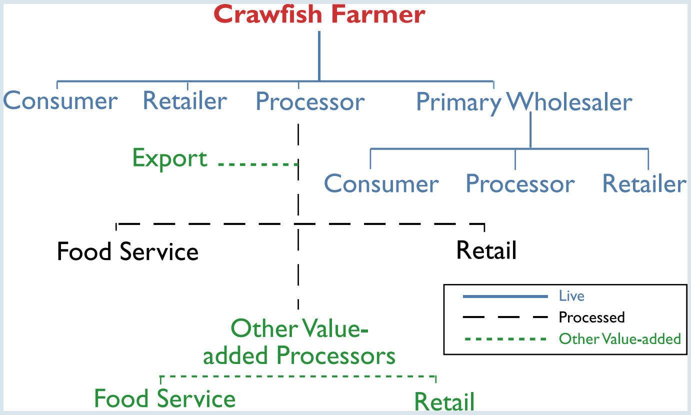


Figure 10.3. Marketing avenues for Louisiana crawfish.

stores, restaurants and consumers. In Louisiana, red swamp crawfish have higher consumer appeal in the live market than white river crawfish, although this distinction is usually not made outside of traditional southern Louisiana markets.

Highest demand by retail consumers and restaurants is on weekends, even in Louisiana, with limited retail sales early in the week. The live product, with its restricted shelf life of no more than several days, largely dictates harvesting schedules and market plans. Shelf life of the live product also effectively limits regional and national distribution.

Whether served in households or retail outlets, live crawfish are typically boiled (or steamed) and consumed hot and fresh in a festive atmosphere (Figure 10.4). Crawfish are not considered a staple food; rather, they are generally associated with social occasions, and no food exemplifies the Cajun cultural atmosphere like fresh, boiled crawfish coupled with its requisite condiments of spicy vegetables and cold beverages.

Processed and prepared products

When crawfish are abundant or when live markets become saturated, a portion of the annual crop is processed and sold as fresh or frozen abdominal or "tail" meat. The most popular processed product is cooked, hand peeled and deveined meat

Figure 10.4. Cooking, peeling and eating whole boiled crawfish is a common springtime weekend activity in Louisiana.

that is usually sold in 12-ounce or 1-pound packages (Figure 10.5). Tail meat may be packed with or without hepatopancreatic tissue (in Louisiana frequently referred to as "fat"), which is an important flavoring condiment in Louisiana cuisine and is savored for its distinctive rich flavor. The smaller size classes of crawfish are usually those processed for the tail meat market, leaving the larger individuals for the more profitable live market.

Figure 10.5. The most popular processed product is cooked, hand-peeled and deveined meat that is usually sold in 12-ounce or 1-pound packages.

The abdominal meat yield for cooked crawfish is, on average, about 15 percent of live weight, but meat yield varies with factors such as sexual maturity and size. Immature crawfish generally yield 4 percent to 5 percent more meat than mature individuals because they have smaller claws and thinner shells. Cooking time and peeling technique can also influence meat yield because all processing is by hand. Early in the production season (November-March) when a high percentage of the crawfish are immature, meat yield can be as high as 22 percent to 23 percent. Late in the season (April-July) when most crawfish are mature and have heavier exoskeletons and large claws, meat yield can be as low as 10 percent to 12 percent of body weight. Abdominal meat is used in diverse ways and can be an appropriate substitute in many shrimp recipes. The amount of crawfish processed for tail meat in Louisiana varies annually, but since the introduction of inexpensive procambarid crawfish meat from China, it is estimated that less than 10 percent of the annual crop is now processed for meat.

Another product form is cooked whole crawfish, usually served fresh and hot, with small volumes also sold as frozen product later to be warmed and served. Traditionally, crawfish in the southern United States are cooked with red pepper-based spices/seasonings, often with onions, potatoes and corn that complement the meal. The consumer extracts the edible portions of the whole crawfish by hand (Figure 10.6).

Increasing in popularity in Louisiana, and within the range of delivery for live crawfish outside of Louisiana, are retail outlets and restaurants serving hot, boiled crawfish. Small, seasonally "take-out" outlets (Figure 10.7) have developed wherever live crawfish can be readily obtained, and many businesses also cater boiled crawfish to large groups, parties and festivals using custom boiling rigs (Figure 10.8).

Prepared frozen crawfish dishes, although still only encompassing a small portion of total sales, have helped increase the distribution of processed abdominal crawfish meat through value-added products.

Marketing Influences

Marketing of domestically produced crawfish has been complicated in recent years by imports of crawfish products. Millions of pounds of imported frozen processed meat and whole boiled procambarid crawfish, principally from the Peoples Republic of China, are imported into the United States

Figure 10. 6. Crawfish being processed ("peeled") to obtain abdominal ("tail") meat.

Figure 10.7. Small retail outlet specializing in boiled crawfish.

Figure 10.8. Custom mobile crawfish boiling rig used for catering large crawfish boils.

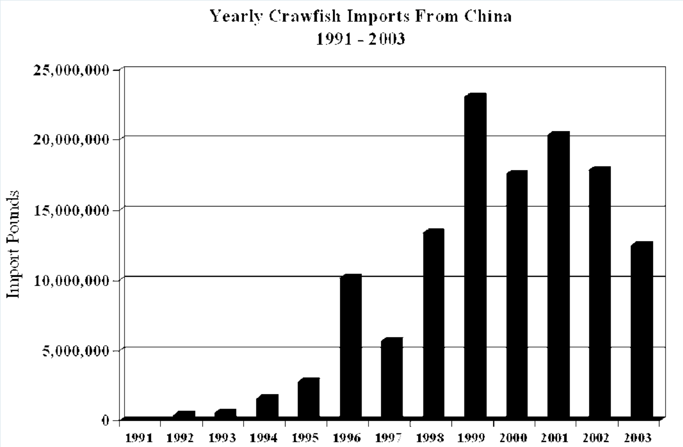


Figure 10.9. Imports of Chinese crawfish (tail meat and whole, boiled product) into the United States (Source: Port Import Export Reporting Service, PIERS, a division of the "Journal of Commerce").

annually (Figure 10.9). Although a tariff has been imposed by the United States Department of Commerce on much of the imported Chinese crawfish meat, damage to the U.S. industry has occurred. Prior to Chinese imports over 100 licensed crawfish processors existed in Louisiana. Today, the number of processors number in the low 30s and this has lead to dramatic reduction in processing (peeling) capacity in Louisiana. As a consequence, each year thousands of tons of smaller crawfish are not harvested for lack of adequate live markets and processing infrastructure.

Although demand for crawfish in Louisiana is high, and markets are expanding in adjacent states, on a national basis, crawfish are in direct competition with products such as shrimp, prawns, lobster and crabs. Unlike Louisiana, the public in other states have historically and culturally not consumed crawfish. Nonetheless, crawfish imports provide for year-round availability and more stable prices, which reportedly have had some positive influences in development and expansion of new markets for crawfish products outside of traditional crawfish consuming areas. The growing popularity of southern Louisiana "Cajun" and "Creole" cuisine throughout the United States offers excellent opportunity for expanded market development and sale of both live and processed domestically produced crawfish products in the southern United States and elsewhere.

Pricing

Supply and demand relationships are reflected in price variations from year to year and from week to week during the crawfish harvest season. In Louisiana, average annual pond bank price paid to producers from 1997 through 2005 has averaged between $0.55 and $0.82 per pound, when annual supply ranged from 70 to 85 million pounds, except in 2000 and 2001 when low supply from both aquaculture and the wild crop pushed average statewide wholesale prices over $1.24 per pound (Table 10.1). Seasonally, prices to producers are highest in winter and early spring when supply is relatively low (Figure 10.1 and Table 10.2). Prices decline significantly in late spring and summer when supply peaks and the supply and demand for other locally produced fresh seafoods such as shrimp and crabs increase. In Louisiana, price declines as high as 40 percent to 55 percent for "field run" crawfish can occur within several weeks during peak production (April and May) if crawfish quality (usually size) decreases, but the drop in price for larger crawfish is usually substantially less. In recent years, large crawfish have commanded a wholesale price 2 to 3 times higher than paid for medium to small crawfish.

Although prices for live crawfish are relatively uniform among wholesale buyers from day to day or week to week, no single buyer or group of buyers exerts excessive control over pond-bank prices. But when crawfish supplies are high, wholesalers and processors do have the ability to exert price leverage on producers, and this is usually based on their ability, or inability, to move large volumes of crawfish in the live market. Some buyers offer premium prices for their larger, more loyal or more consistent suppliers.

Although wholesale prices for peeled crawfish tail meat are not published, prices typically track the price of live product and, as a "rule of thumb," the wholesale price of a pound of tail meat is 10 to 12 times higher than the wholesale price of a pound of live crawfish.

Table 10.1. Average annual supply and wholesale price for live crawfish in Louisiana from aquaculture and the wild commercial fishery, 1997 through 2005.

	Source					
	Aquaculture		Wild Fishery		Total	
Year	Pounds (millions)	$/Pound	Pounds (millions)	$/Pound	Pound (millions)	$/Pound
1997	46.9	0.60	30.1	0.52	77.0	0.57
1998	36.1	0.62	30.2	0.63	66.3	0.63
1999	41.2	0.66	21.2	0.65	62.4	0.66
2000	16.2	1.75	2.3	1.48	18.5	1.71
2001	27.7	1.33	6.4	0.84	34.1	1.24
2002	60.5	0.82	14.0	0.52	74.5	0.76
2003	73.0	0.65	10.2	0.52	83.2	0.63
2004	70.0	0.60	8.3	0.58	78.3	0.60
2005	73.8	0.55	8.1	0.57	81.9	0.55

Source: "Louisiana Summary: Agriculture and Natural Resources," Louisiana State University Agricultural Center, Baton Rouge, Louisiana.

Table 10.2. Estimated average monthly wholesale price and maximum and minimum prices for live "field run" crawfish (mixed sizes) in southern Louisiana, 2000 through 2005.

Price	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Average	$1.65	$1.28	$1.16	$1.07	$0.82	$0.61	$0.54	$0.60	$0.50
Maximum	$2.00	$2.00	$1.33	$1.21	$0.90	$0.75	$0.65	$0.72	$0.50
Minimum	$1.42	$0.95	$0.88	$0.92	$0.68	$0.53	$0.38	$0.47	$0.50

Source: Aquaculture Research Station and Rice Research Station, LSU AgCenter, Baton Rouge, Louisiana and Crawfish Research Center, University of Louisiana at Lafayette, Lafayette, Louisiana.

Production Strategies for Identified Markets

A crawfish producer should be familiar with potential markets, both wholesale and retail, and match production to estimated needs. Since crawfish are harvested several times per week, reliable buyers are paramount to a farmer's success. Direct sales to retail customers by farmers are not particularly high in large production areas like southern Louisiana. Therefore, most large producers in these areas must sell most of their harvest to wholesale buyers and processors. Small-scale crawfish producers outside of Louisiana have few established and knowledgeable wholesalers who are experienced in marketing live crawfish. Many small-scale producers, however, have successfully developed markets for both direct retail sales to consumers and to retail seafood establishments.

Occasionally, harvesting schedules and strategies must be adjusted to accommodate available markets. Buyers may prefer to have product delivered only on certain days, such as Thursday through Sunday. Additionally, market demand for crawfish early in the season may allow for various sizes of crawfish to be sold with little problem, but when crawfish supplies are more abundant, trapping strategies may need to be adjusted to maximize crawfish sizes, even at the expense of overall yield. Planning and good communication with potential buyers early in the season can allow trapping strategies to be developed that respond to market preferences and improve a producer's competitive position.

Regulations and Permits

Various permits may be required to market crawfish, such as wholesale or retail fish distributor's license, or to transport them across state lines. Permits are specific for each state. Imports of live non-native crawfish are restricted or forbidden in a number of states, especially where there are concerns over establishment and competition with native species. Before shipping live crawfish, always verify regulatory requirements in the receiving state, or states in which crawfish are being transported, to avoid serious legal problems.

In Louisiana, live haulers are usually required to possess permits or licenses to transport crawfish, depending on whom their crawfish are being purchased from or sold to. These may include municipal or parish permits as well as a state transport license and seafood wholesale/retail dealer's license. For interstate shipments of live crawfish, pass-through states and the receiving state also will likely have license requirements.

Transport and Storage

Storage and transport of live crawfish is unusual in that they are not transported in water, but rather consolidated in plastic mesh sacks (Figure 10.10). Sacks hold about 35 to 45 pounds of crawfish depending on how tightly the trapper

Figure 10.10. In Louisiana, crawfish are transported to market and sold as a live product, in mesh bags (sacks) that usually hold 35 to 45 pounds of crawfish.

chooses to pack them. This method is preferred over more rigid containers such as totes (Figure 10.11) because crawfish can be packed in the sacks in a manner that prevents damage from pinching, which can happen when animals are not sufficiently restricted.

To minimize crushing, sacks should not be packed too tightly, but sufficiently tight to restrict crawfish movement. Sacks of live crawfish can be transported in open bed trucks for short distances, but sacks should be covered with a tarp to minimize drying of gills. Wholesalers or jobbers haul sacks of live crawfish over long distances, or in larger quantities, in insulated trucks, with or without refrigeration (Figure 10.12). Crushed ice is placed over the sacks in nonrefrigerated trucks and, in some cases, refrigerated trucks, to reduce crawfish metabolism and maintain a high level of humidity, which increases shelf life of live crawfish.

High survival rate during live transport begins by insuring crawfish are harvested from ponds with good water quality. Live crawfish should be transported to on-the-farm coolers or to the terminal market as soon after harvest as possible. Transport vehicles should be clean and free from petroleum products or other contaminates. If hauled long distance in the harvest boat or transported in an open vehicle, exposure of crawfish to excessive wind and bright sunlight should be minimized by covering the sacks with wet burlap or a tarp. Sacks should not be stacked so high that crawfish in the bottom sacks are crushed.

Figure 10.11. Crawfish totes, an alternative method for holding and transporting crawfish.

Figure 10.12. Crawfish transport truck and transport with ice.

Sacks of live crawfish in good physical condition can be held in high humidity coolers at 38 F to 46 F for up to several days prior to peeling or further transport to the terminal destination. Maintenance of gill moisture is crucial for survival of crawfish held in coolers. Gill moisture is usually accomplished by periodic wetting of crawfish and/or placement of wet burlap or ice over the sacks of crawfish. If placed in plastic tote boxes, the top tote should be filled with ice. Melting ice trickles down through the totes to provide the necessary moisture. Placing unchilled crawfish in totes is not recommended because physical damage from pinching by active crawfish may occur.

A relatively small volume of live crawfish is shipped in sacks by air-freight throughout the United States in insulated seafood shipping boxes containing frozen gel packs. During warm weather, crawfish shipped by air freight should be cooled overnight prior to shipping.

Purging and Cleaning

To provide a more appealing product for live markets, a small number of producers have adopted the practice of "purging" crawfish before selling them. This requires that crawfish be confined in water or very humid environments where food is withheld for 24 to 48 hours. This process cleans the exoskeleton of mud and debris and eliminates or reduces digesta in the intestine (Figure 10.13), which consumers may find unappealing. This method should not be confused with the practice of immersing crawfish in salt water immediately before boiling, which is not effective in evacuating the gut and is little more than an external wash.

To facilitate removal of the intestinal contents, crawfish are commonly held in tanks within specially constructed boxes or baskets (Figure 10.13) that are usually suspended in water. Recommended loading rate is about 1.5 pounds of crawfish per square feet of submerged surface area with adequate aeration and water exchange. Equally effective, but seldom used, is a water spray system where crawfish are held in shallow pools of water (1/2-inch deep) under a constant spray or mist. Holding crawfish in aerated vats or purging systems under crowded conditions for more than 24-48 hours is not recommended because of the possibility of excessive mortality. Though purging increases the cost of the product, purged crawfish have high consumer acceptance, particularly outside of traditional Louisiana markets. Some people who have eaten crawfish for many years are accustomed to nonpurged crawfish and do not find them objectionable; nonetheless, many would probably prefer purged product if cost was reasonable.

Although the current market for purged crawfish is small from a lack of public awareness and price differences (15 percent to 25 percent higher), purging has contributed to repeat sales and loyalty to certain producers or distributors. Mortality during purging is the largest contributor to increased prices, but

Figure 10.13. Purged versus nonpurged crawfish (top photo). Note the difference in the intestinal contents of nonpurged crawfish (left) and purged crawfish (right). Crawfish purging system (bottom photo).

research has recently demonstrated that shorter purge duration (12 hours) can be nearly as effective and contributes significantly to less mortality.

The external surfaces of crawfish, which can be fouled and/or stained, are reasonably cleaned during purging. Abrasive actions of crowded crawfish rubbing against one another effectively "polish" the shells. For nonpurged animals and excessively stained batches of crawfish, however, additional cleaning is sometimes accomplished prior to cooking. External cleaning of the carapace of live crawfish with food-service chemicals (ascorbic or citric acid and baking soda) to enhance appearance and increase marketability is becoming increasingly common.

Grading

Crawfish markets have changed considerably since the mid-1980s when crawfish were sold without consideration of size. Development of an export market in Scandinavia in the late 1980s for crawfish 15-count (number per pound) or larger, first provided the impetus for size grading. Louisiana's export markets for crawfish were eventually lost to competition from the Peoples Republic of China, but size grading remained and is widely used in the domestic market. Grading by size is usually not practiced early in the production season when crawfish supply is low and demand is high for crawfish of all sizes, but as the volume of crawfish increases in early spring size grading becomes a standard practice for servicing the market demand for large crawfish. Nearly all grading occurs at wholesale outlets or processing plants, using modified vegetable graders or custom-made graders (Figure 10.14).

Figure 10.14. Large commercial grader at a crawfish buying dock.

At present, no uniform size and grade standards exist for the crawfish industry as with other seafoods, and this to some degree hinders out-of-state market development and expansion. Based on a number of production and marketing conditions, crawfish are typically graded into two or three size classes. Generally, the largest crawfish are sold to specialty restaurants, and the smaller ones are processed for tail meat or blended with larger individuals for large volume sales. One example of a commonly used grading system for crawfish in Louisiana is shown in Table 10.3. Other grading standards are used by various crawfish wholesalers depending on their markets.

Table 10.3. Example of a common grading system used for live crawfish in Louisiana.

Size Classification	Size Classification by Number	Number (Count) of Crawfish per Pound
Large	1	15 or fewer
Medium	2	16-20
Small	3	21 or more
Field run		Mixed sizes

Glossary

Abdomen – Refers to the tail of a crawfish. Used in locomotion and swimming. Peeled after cooking for consumption.

Age class – Also synonymous with size class, recruitment class. Generally refers to pulses or "waves" of crawfish hatched around the same time. For example, if large numbers of crawfish were hatched and released into the water in the first two weeks of October and the last two weeks of November, two age classes of juvenile crawfish would be in the pond. (Also see "Recruitment.")

Agronomic – Refers to terrestrial plant agriculture.

Aquaculture – Cultivation of aquatic organisms in a controlled and managed environment.

Baffle levees – Small levees built within the interior of a crawfish pond to direct water flow when pumping water into ponds. They also serve as reproductive burrowing area for crawfish.

Biomass – The weight of all the organisms forming a given population or inhabiting an environment. Can also be used to describe the total quantity or weight of plants, as in biomass of the forage crop.

BMP – "Best Management Practices"; procedures followed by agricultural producers to control the generation and delivery of pollutants from agricultural activities into water resources of the state thereby reducing the amount of agricultural pollutants entering surface and ground waters.

Best management practices – see "BMP."

Burrow – A hole or excavation in the ground made by a crawfish for reproduction, shelter and habitation.

Broodstock – Reproductively active adults or immature sub-adults obtained for breeding.

Cannibalism – Eating of a crawfish by another crawfish. Crawfish are most vulnerable to cannibalism after molting.

Carapace – External upper shell of a crawfish.

Clay loam – A soil that consists of about 20% to 45% sand and 27% to 40% clay.

The fossil record suggests that crawfish and their relatives have been around for 285 million years.

The red swamp crawfish (rear) and white river crawfish (front) are closely related and often occur side-by-side, but natural hybrids between the two have never been documented.

Count per pound – Number of crawfish that equals 1 pound in weight. Often referred to as simply "count." For example, 20-count per pound crawfish or 20-count crawfish will consist of 20 crawfish that collectively weigh 1 pound.

Crop rotation – Agronomic term that refers to growing a different agricultural crop following the harvest of a crop, usually in the same field. Growing crawfish in a rice field following the harvest of rice grain is an example of a crop rotation.

Density – Number of individual crawfish per unit space area.

Density dependent growth – A term that means that the growth rate of a crawfish is dependent on the overall population density of crawfish in the pond. The higher the density the slower the growth and vice-versa.

Detritus – Organic debris from decomposing plant and animal material. Detritus has many microorganisms and can be used a food by crawfish directly or is used as food by other organisms that crawfish eat.

Detritivores – Organisms that eat detritus.

Dewatering – To remove water from a pond or field by draining.

Dissolved oxygen – Oxygen gas dissolved in water and is required by crawfish for respiration and survival. Often referred to as "DO." Low dissolved oxygen is detrimental to the health and survival of crawfish.

Ecosystem – A community of organisms, interacting with each other, plus the environment in which they live and with which they also interact.

Effluent – Water that is discharge or released into the environment from a crawfish pond. Also referred to as "tailwater."

Epiphytic organism – Refers to organisms growing on the outside of a plant, not as parasites, but as using it for support. For example, algae growing on the outside of a rice plant is an epiphytic organism.

Exoskeleton – External shell covering the outside of a crawfish.

Fallow – Usually refers to cultivated land that is allowed to lie idle following the harvest of another crop.

Fat – Common reference for the hepatopancreas. Sometimes referred to by scientists as the digestive gland or organ.

Fecundity – Number of mature eggs or oocytes in a female crawfish just prior to spawning.

Formulated feed – A food that is manufactured from various ingredients and meets most, or all, of the nutritional requirements of an animal. It may also be referred to as manufactured feed.

Filter strip – Usually refers to a vegetated strip of land through which or over which effluent or tailwater can flow to remove suspended matter and nutrients.

Flushing – To replace all or a portion of water in a pond, usually in an attempt to increase the dissolved oxygen content.

Food chain – Chain of organisms through which nutritional energy is transferred. Each link in the chain feeds on and obtains energy from the one preceding it and in turn it is eaten by and provides energy for the one following it.

Food web – All the food chains in a crawfish pond make up the food web.

Gastroliths – Two small mineral stones found in the stomach lining of a molting (soft) crawfish. They consist largely of calcium minerals that are extracted from the old shell prior to molting. The gastroliths dissolve as the crawfish hardens to return calcium to the newly formed shell.

Genotype – The genetic makeup of a particular organism.

Germination – Process by which a seed sprouts.

Habitat – The environment where a plant or animal normally lives and grows.

Hatchlings – Refers to juvenile crawfish as they emerge from hatched eggs. They may be referred to as "hatchlings" for several weeks.

Hepatopancreas – A glandular organ in a crawfish that aids in the digestion of food. It has the same function as the liver and pancreas and acts as a reserve for stored energy. It supplies a significant amount of nutritional energy to crawfish when they are in burrows, and it is also important in crawfish reproduction. In southern Louisiana it is commonly referred to as "fat."

On extremely flat lands, water can be circulated and aerated using paddlewheels designed for catfish production.

Natural surface waters provide a resource for flooding and flushing crawfish ponds in many parts of the state.

Herbivores – Organisms that eat plants.

Holdover crawfish – Crawfish that survive the previous production season, successfully burrow, and can be found in the current season's crawfish crop. Holdover crawfish may be mature or immature.

Hybrids – Animals or plants resulting from the cross of parents that are genetically different, as in a cross of two different species.

Hydrological cycle – As it relates to crawfish production in Louisiana, the hydrological cycle refers to the annual summer low water and spring high water cycles in Louisiana's Atchafalaya River Basin on which the annual wild crawfish crop is predicated.

Hypothesis – A tentative assumption made from an interpretation of a practical situation or condition.

Invertebrate – A collective term for all animals that do not have vertebrate (spinal column).

Intercropping – Growing of two or more different crops in the same field simultaneously. For example, relaying stunted crawfish into the same field as an actively growing rice crop is an example of an intercropping system.

Intermolt – Stage in the molting cycle of crawfish between the post-molt and next pre-molt stage. In the intermolt stage the crawfish does not increase measurably in length but will increase in tissue weight with proper nutrition and environmental conditions.

Juveniles – A term used to refer to crawfish that have not yet attained sexual maturity or adult stage.

Levee – An earthen embankment for impounding or holding water.

Intermittent harvesting – A process in which crawfish are harvested intensely for several or more days followed by a rest period of several days or more in which no harvesting occurs to allow for additional growth in individual crawfish.

Life cycle – The series of stages an organism passes through during its lifetime.

Lodging – The leaning or falling over of plants, particularly cultivated crops like rice or sorghum-sudangrass.

Metabolism – The general chemical processes occurring within a living organism.

Microorganism – Microscopic organism; a unicellular plant, animal or bacterium.

The three-funnel pyramid trap represented an important innovation in trap design and harvest efficiency. The version pictured here has since been replaced by newer variations on this design, using square mesh wire and plastic collars which also serve as handles.

Molting – To shed or cast off the old exoskeleton periodically to allow the body to grow.

Monocropping – Cultivation of a single agricultural or aquacultural crop in a field or pond. Also known as "monoculture."

Noxious weeds – Nondesirable plants present in crawfish ponds or agricultural fields; examples include cattails, indigo weed, water lilies.

Omnivores – Organisms that eat both plant and animal matter. Crawfish are considered to be omnivores.

Organic – Any material derived from living organisms.

Ovary – The organ in female crawfish that produces ova or eggs.

Oxygen demand – Oxygen consumed in respiration by all organisms in a crawfish pond. The higher the oxygen demand the more difficult it is to maintain oxygen levels in the water. Also commonly referred to as "Biochemical Oxygen Demand" or "BOD."

pH – A measure of the acidity or alkalinity of soil, water or solution. Values range from 0 to 14 with 7 being neutral, less than 7 is acidic and above 7 is alkaline.

Pathogen – A specific agent or organism that causes infectious disease in crawfish.

Perimeter levees – The larger levees that define the outside boundary of a crawfish pond. Perimeter levees are usually higher and wider than interior baffle levees.

Pesticide – A chemical or biological agent used to destroy pests. Pesticides include fungicides, herbicides and insecticides.

Plankton – Microscopic plants and animals present in water.

Population dynamics – A term that refers to the rates of abundance, reproduction, growth and mortality in crawfish populations.

Population structure – A term that refers to the age, size and number of crawfish in a pond population.

Procambarid – A taxonomic classification term that includes both the red swamp crawfish and white river crawfish. Other species of crawfishes are procambarids in Louisiana and elsewhere.

Purging – Process of cleaning crawfish by water immersion or spray immersion to empty the intestinal (gut) contents of fecal material as well as removing mud and grit from the gill cavity.

Ratoon – Refers to the regrowth of rice plant from the stalks after grain harvest.

Recruitment – Entry of young-of-the-year crawfish ("recruits") into the population as they leave their mother when she emerges from a burrow and enters the open water of a pond. Pulses of recruits that enter the population throughout the various months in a production season are referred to as "recruitment waves" or "waves of recruitment." (Also see "age class.")

Relaying – The process of transferring small crawfish from ponds deficient in food into other ponds or fields with few crawfish, and where food is abundant, to stimulate growth.

Senescence – The process of aging leading to death after the completion of growth in plants.

Silty clay - A soil that consists of about 40%-60% silt and 40%-60% clay.

Set-time – The number of hours that a baited crawfish trap is left in the water to catch crawfish before being emptied and re-baited. Usually trap set times are approximately 24 or 48 hours. May also be referred to as "soak-time."

Specimen – An individual considered typical of a group.

Spawn – To produce and deposit eggs in the reproduction process.

Standing stock – Refers to either the number or weight of crawfish in a pond or field at any particular moment in time.

Stunting – A term that refers to a significant reduction in the growth of a population of crawfish, usually associated with high density and deficient food resources.

Suspended sediments – Clay, silt, sand particles suspended in water.

Swimmerets – Small appendages under the abdomen (tail) of a crawfish that function in locomotion and reproduction. Eggs when laid are attached to the swimmerets. (Also known as "pleopods.")

Terrestrial grasses – Volunteer (nonplanted and noncultivated) grasses of nonaquatic origin that usually grow in the pond during the summer dry period when no water is present.

Toxicant – A toxic compound.

Tailwater – Water that is discharged or released into the environment from a crawfish pond. Also referred to as "effluent."

Turbidity – Opaqueness in water caused by suspended particles from bottom muds or organic matter such as plankton.

Wetland – A land or area containing a significant amount of soil moisture. The federal government has specific criteria for defining wetlands that are used in regulatory matters.

Young-of-the-year – A term that refers to hatchling or juvenile crawfish hatched within the current crawfish production season.

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