Rice Production in Florida: A Handbook

University of Florida – Institute of Food and Agricultural Sciences

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Executive Summary

This is a handbook that covers topics related to rice production in South Florida, specifically in the Everglades Agricultural Area. With rice acreage and production on the rise in the past ten years it is important to formulate information that researchers, growers and public can use related to rice production. Some of the topics covered in this handbook include rice variety trials, water management, nutrients, pest and disease management, and information related to post-harvest processing. The information provided in the handbook will be updated annually to include new topics with the help of UF-IFAS faculty and extension agents.

Acknowledgements

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CONTENT

	Topic	Author(s)
1.	Rice Variety Assessment Trials in the Everglades Agricultural Area, 2015-2017	Matthew T. VanWeelden
2.	Water Management for Rice Cultivation	Jehangir H. Bhadha
3.	Rice Nutrition	J. Mabry McCray
4.	Insects in Florida Rice	Ronald Cherry and Julien Beuzelin
5.	Common Diseases in Rice	Richard N. Raid
6.	Production and Post-harvest Processing of Rice	Sangeeta Mukhopadhyay

Rice Variety Assessment Trials in the Everglades Agricultural Area, 2015-2017

Author: Matthew T. VanWeelden

Introduction:

Rice acreage in the Everglades Agricultural Area has been steadily increasing over the past decade, with 11,912 acres in 2008 and 22,861 acres in 2015. Approximately 29,000 acres of rice were planted in 2017. Because Florida does not have a dedicated breeding program, varieties from other state breeding programs, such as Louisiana, Texas, and Arkansas, are assessed in annual variety trials to determine general performance, grain yields, and disease susceptibility.

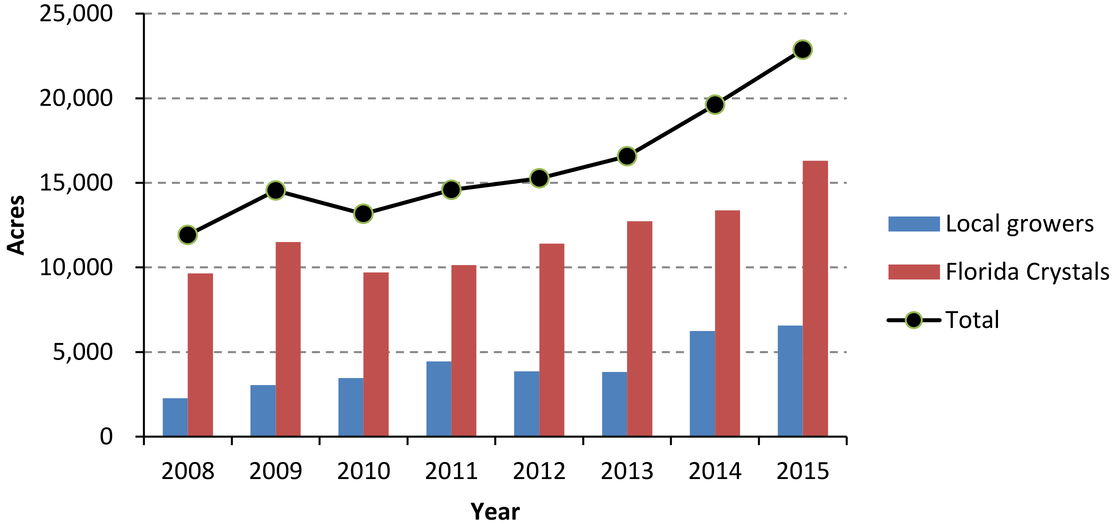

Fig. 1 Total rice acreage planted in the EAA between 2008 and 2016. (Credit: Jehangir Bhadha, Matthew VanWeelden, and Luigi Trotta)

Overview of Rice Variety Assessment Trials:

The following are the results from the rice variety assessment trials conducted from 2015–2017 in collaboration between the University of Florida and Florida Crystals Corporation. In all years, trials were arranged using a randomized complete block design with four replications. Rice varieties were randomized to 6-ft by 20-ft plots (6 rows) and planted at a rate of 90 lbs/acre for conventional varieties and 35 lbs/acre for hybrid varieties. Trials were subjected to continuous flooding 21 days after planting. At harvest, panicles were removed from the middle 10-ft of the inner 2 rows, threshed, and dried. Finally, dried grains were weighed and sample yields were extrapolated to estimate DW/acre.

Fifteen varieties were evaluated in 2015, with yields ranging from 3,666 to 5,215 lbs DW/acre (Fig. 2). CL-151, Rondo, and LaKast, all late-maturing varieties, yielded the highest lbs DW/acre, while Caffey, CL-271, and Jupiter, also late-maturing varieties, yielded the lowest. Recommended varieties in 2015 based on results from the variety assessment trials included CL-151, Rondo, LaKast, RU-4077, CL-163, and Rex.

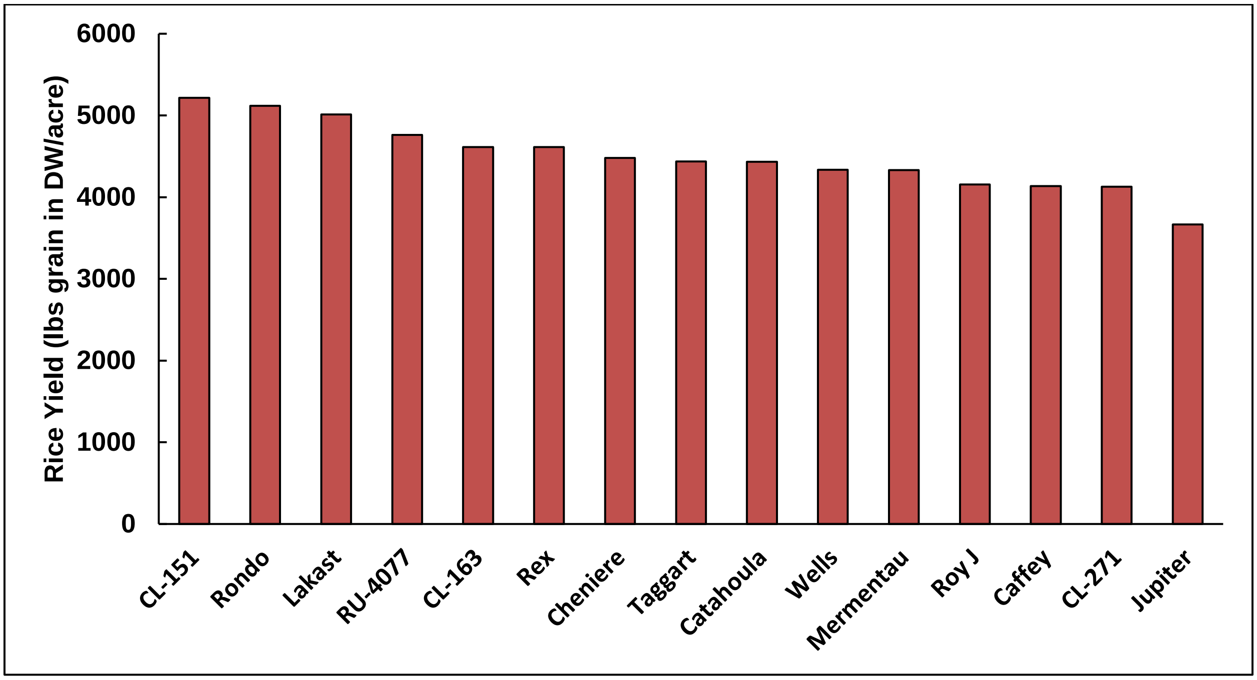

Fig. 2 Average rice yields from the 2015 rice variety assessment trials.

In 2016, RiceTec varieties XL4534 and XL753, Texas varieties Dixiebelle, Presidio, and Sierra, Arkansas variety LaKast, Clearfield varieties CL-153 and CL-272, and Crop Production Services (CPS) 13-323-66 were added to the rice variety assessment trials. Wells, Rondo, and CL-163 were excluded from 2016's trials. Yields ranged from 3,496 to 7,079 lbs DW/acre, with CL-271, Taggart, and Rex yielding the highest (Fig. 3). Early maturing varieties XL4534, XL753, and 13-323-66 yielded the lowest, however these varieties sustained significant grain loss from bird feeding. May plantings exhibited greater average yields (6,510 lb DW/acre) than April plantings (4,829 lb DW/acre). Recommended varieties in 2016 included CL-271, Taggart, Rex, CL-151, Cheniere, Roy J, and CL-153.

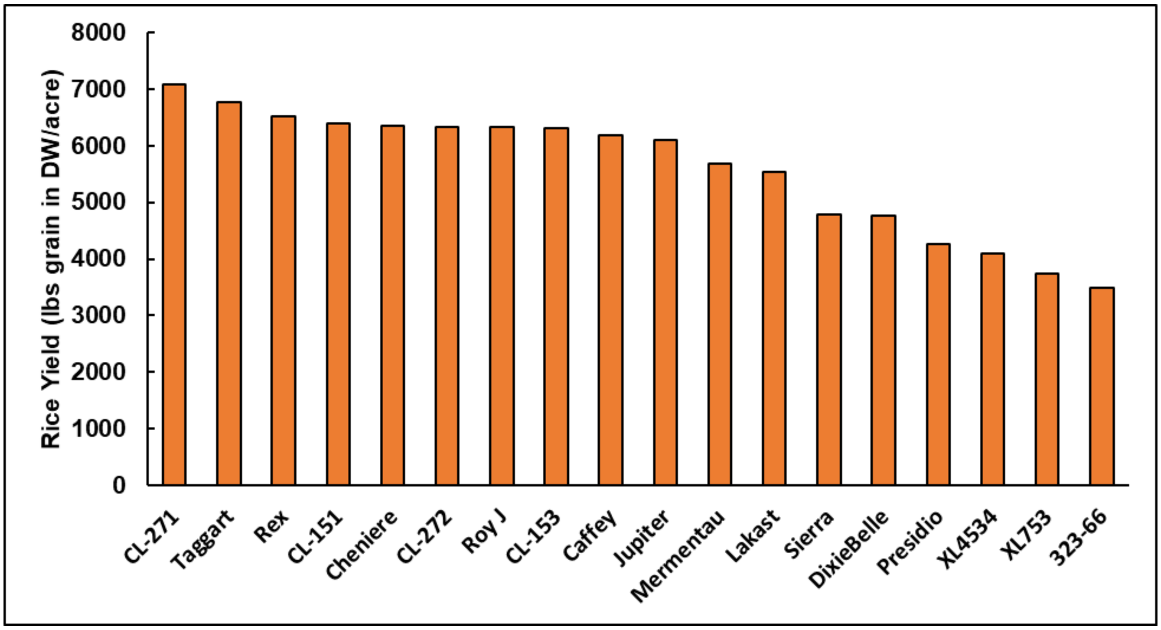

Fig. 3 Average rice yields from the 2016 rice variety assessment trials.

In 2017, RiceTec variety XL760 and Arkansas varieties Diamond and Titan were added to the rice variety assessment trials. Yields averaged between 7,079 and 3,496 lbs DW/acre, with XL760, XL753, and Cheniere yielding the highest among all varieties (Fig. 4). XL753 yielded an average of 2,250 lbs DW/acre greater than in 2016. For the second year in a row, XL4534 remained one of the three lowest yielding varieties. Average rice yields were greater when planted in May (6,436 lbs DW/acre) versus planting in March (4,464 lbs DW/acre) or April (4,285 lbs DW/acre). Recommended varieties in 2017 included XL760, XL753, Cheniere, CL-151, Titan, and Jupiter.

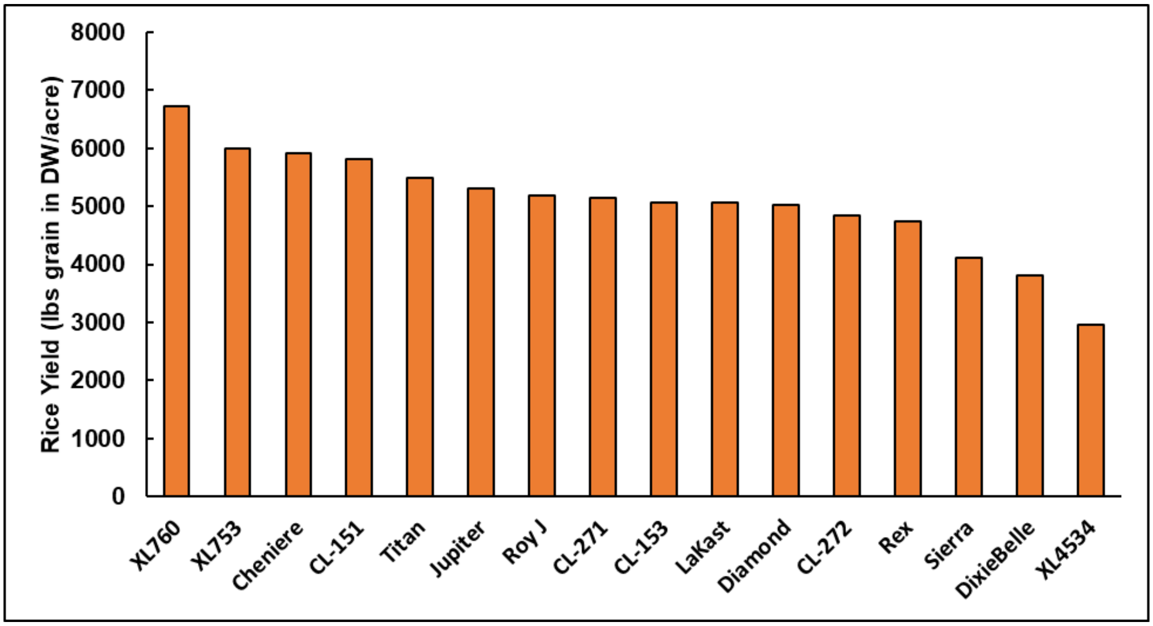

Fig. 4 Average rice yields from the 2017 rice variety assessment trials.

Water Management for Rice Cultivation

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Background:

Flooded rice is typically grown in bunded fields that are continuously flooded up to 14-21 days before harvest. Continuous flooding helps ensure sufficient water and control weeds. It is also known to suppress insect population that would otherwise thrive in drained soils. On average, a single crop of rice requires approximately 1,400 L (370 gal) of water to produce 1 kg (2.2 lb) of rice in an irrigated production system (International Rice Research Institute, IRRI). Seasonal water input to rice fields can vary from as little as 40 cm in heavy clay soils with shallow groundwater tables to more than 200 cm in coarse-textured (sandy or loamy) soils with deep groundwater tables. For muck soils (Histosols) in Florida, water inputs depends on the thickness of the soils ranging anywhere between 40-200 cm. Underneath the muck soils is a confining layer of limestone that acts as a hardpan and prevents seepage. Irrigated rice receives an estimated 34−43% of the total world's irrigation water, or about 24−30% of the entire world's developed fresh water resources (IRRI).

To effectively and efficiently use water and maximize rice yields, the following good water management practices can be followed:

1. *Construct field channels to control the flow of water to and from the field.*

It is important that water can be delivered to the rice field and discharged out of it with utmost efficiency and speed. Creating 20-25 cm deep channels within the rice fields allows for fields to be drained and flooded easily.

2. *Till the field to minimize water loss (or create a hardpan).*

It is very important that the fields can retain soil moisture so that the water table can be raised and lowered as required.

3. *Level the fields.*

It is imperative to avoid ponding in rice fields, or have raised patches. A well-leveled field is crucial to good water management.

4. *Construct bund (levees) and fix any cracks or holes.*

It is very important that there are no cracks or holes through which water can seep out of the rice fields. To avoid this, bunds should be built high enough to store water, and any possible cracks or holes should be fixed prior to flooding.

NOTE: Rice is extremely sensitive to water shortage (below saturation) at the flowering stage. Drought at flowering ca result in yield loss from increased spikelet sterility, thus fewer grains.

Different crop establishment methods require different water management practices:

1. *Continuous flooding*

Continuous flooding of water generally provides the best growth environment for rice. For direct seeded rice, fields should be flooded only once the plants are large enough to withstand shallow flooding (3-4 leaf stage). If transplanting, water levels should be around 3 cm initially, and gradually increase to 5−10 cm (with increasing plant height) and remain there until the field is drained before harvest.

2. *Alternate wetting and drying (AWD)*

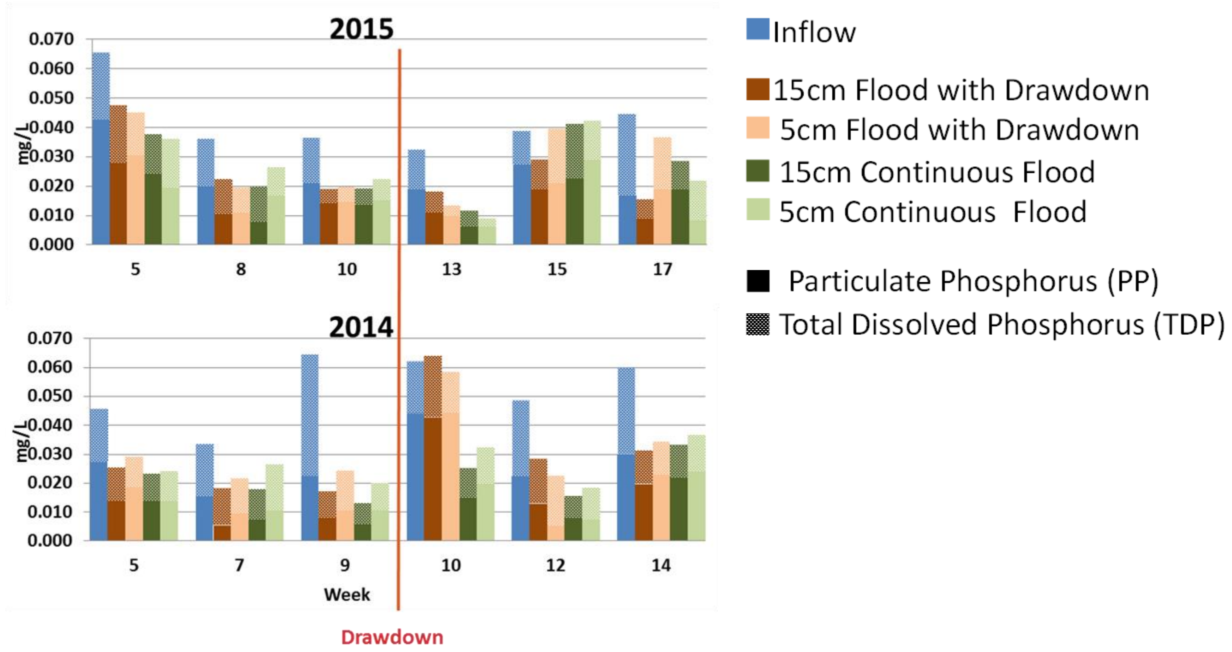
For direct seeded rice, keep the soil moist but not saturated, to avoid seeds from rotting in the soil. After sowing, apply a flush irrigation to wet the soil, if there is no rainfall. Saturate the soil when plants have developed 3-4 leaves. AWD can be started a few weeks (1-2) after planting. Irrigate and then allow the water depth to drop to 15 cm below the surface. Once the water level has dropped to 15 cm below the surface, re-flood the field to a depth of 5 cm above the surface and repeat.

NOTE: one week before and one week after flowering the field should always be flooded.

Utilizing flooded rice to reduce phosphorus loading:

Hypothesis: Since no N, P, K is added prior to planting, rice may help reduce nutrients from the water column.

Study 1



(Tootoonchi et al. 2018)

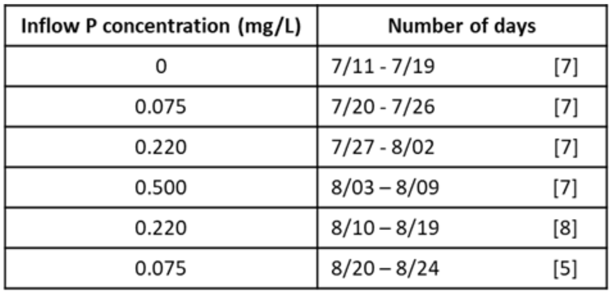
Conclusions:

Total P and total dissolved P concentrations were reduced in both years by 42% and 38%, respectively.

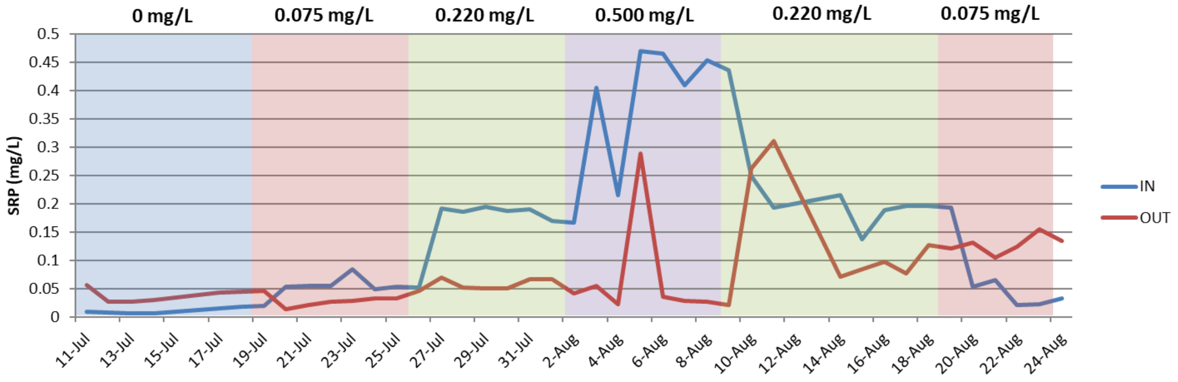
15 cm flood generally had higher reductions of total P and total dissolved P than 5 cm flood.

Drawdown did not show any significant effects on water quality parameters.

Study 2



Inflow P concentration (mg/L)	Number of days
0	7/11 - 7/19 [7]
0.075	7/20 - 7/26 [7]
0.220	7/27 - 8/02 [7]
0.500	8/03 – 8/09 [7]
0.220	8/10 – 8/19 [8]
0.075	8/20 – 8/24 [5]

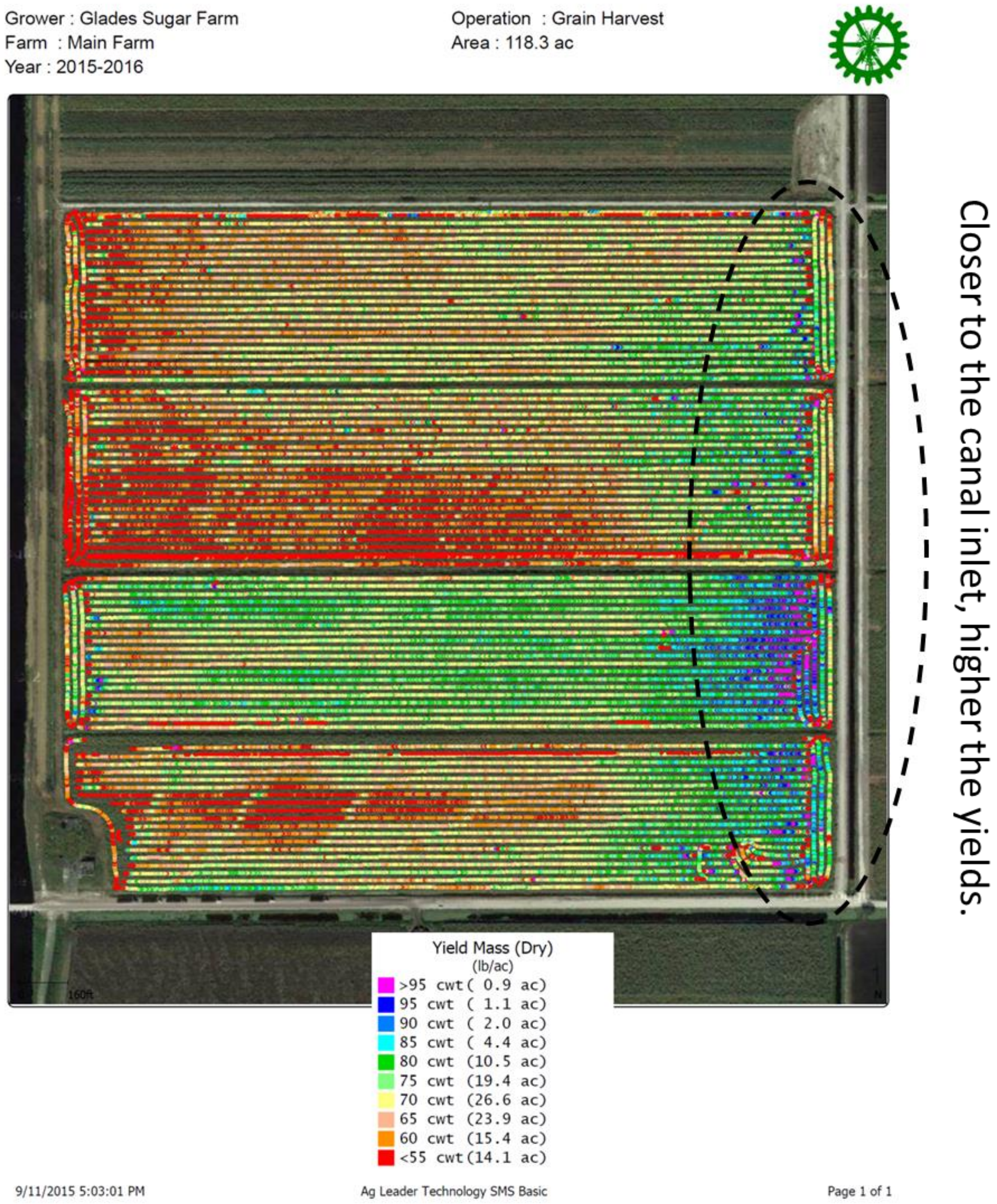


Conclusions:

After an initial increase in soluble reactive phosphorus (SRP) in the outflow water, inflow water concentrations were typically higher than outflow water up to 0.22 mg/L initial P concentrations. This study showed that rice plants took up P for growth, and can potentially improve water quality.

Good water management strategy in the EAA:

1. Keep water at about 3-4 inches (7.5-10 cm) deep.
2. Upwards of 8 inches (20 cm) can cause severe lodging; difficult to harvest; resulting in significant yield loss.
3. Trying to get moisture early in the season is also very critical; yield maps have shown significant higher yields in area that typically have greater soil moisture.


Grower : Glades Sugar Farm
Farm : Main Farm
Year : 2015-2016

Operation : Grain Harvest
Area : 118.3 ac

Closer to the canal inlet, higher the yields.

9/11/2015 5:03:01 PM

Ag Leader Technology SMS Basic

Page 1 of 1

Image courtesy Matt Duchrow.

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Tootoochi, M.,Bhadha, J.H., Lang, T.A., McCray, M.J, Clark, M.W., Daroub, S.H. 2018. Reducing drainage water phosphorus concentration with rice cultivation under different water management regimes. Agricultural Water Management. 205: 30-37. doi.org/10.1016/j.agwat.2018.04.036.

Rice Nutrition

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Silicon:

Silicon (Si) is a beneficial nutrient for rice production and rice plants absorb Si in large amounts. The benefits of Si to rice include improved water use efficiency and increased photosynthetic activity, increased mechanical strength of cells and reduced lodging, and increased resistance to certain insects and diseases. Specifically, Si application has been shown to reduce severity of blast and brown spot diseases and to reduce the requirement for fungicides (Datnoff et al., 1997).

Many organic soils in the Everglades Agricultural Area (EAA) contain very low levels of available Si in their natural state. An exception is the Torry muck soil series which has at least 35% mineral content (composed of clay minerals) as a result of historic overflows from Lake Okeechobee. On organic soils in the EAA, rice and sugarcane yield responses to silica amendment are generally on soils with lower clay mineral content as increased clay mineral content provides increased availability of Si. Rice and sugarcane yield responses to silica amendment can be expected on sand soils also, but in recent years all rice production in Florida has been on organic soils.

Grain yield of rice has been determined to be increased when rice straw at harvest has Si concentration >3%, as compared to Si values below that threshold (Snyder et al., 1986). Rice yields can be increased by as much as 30% by Si amendment when soluble soil Si values are low (Datnoff et al., 1997). Research has shown that calcium silicate is an effective Si amendment but that sugarcane mill ash is not. Silicon recommendations were proposed by Korndorfer et al. (2001) which suggest applying 3.5 and 2.5 tons calcium silicate/acre with acetic acid-extractable soil Si <6 and 6-24 g/m^3, respectively. These are similar to Si recommendations for sugarcane (Table 1) (McCray et al., 2011). These recommendations are for preplant broadcast application and incorporation prior to planting sugarcane, but would also be applicable to application prior to planting rice and should provide adequate Si for both rice and a 3-year sugarcane crop cycle.

Table 1. Calcium silicate recommendations for sugarcane grown on Florida organic soils[a].

Acetic acid-extractable Si	Ca silicate recommendation
g/m^3	tons/acre
0-5	3.0
6-10	2.5
11-15	2.0
16-20	1.5
21-25	1.0
>25	0

[a] From McCray et al. (2011).

Iron:

Iron (Fe) is a micronutrient that is of particular importance to rice production in the EAA. In the 1950's Dr. Victor Green, agronomist at the Everglades Experiment Station (now EREC), noted an incident of a rice crop grown on organic soil that germinated well but then the seedlings turned yellow and when the plants were 4-5 inches tall, the leaves turned white (Green, 1956). Treatments of ferrous sulfate were effective if applied prior to seeding. Later Dr. George Snyder studied this problem and noted that some areas in the EAA had this problem and some did not. Another factor is that flooding favors reduction of Fe to the more plant-available ferrous state, allowing for more Fe uptake, so the most critical time for Fe availability for the rice crop is the seedling stage. Also, Dr. Snyder suggested that the observed rice seedling chlorosis might be a combination of low soil Fe and high soil NO^3-N concentration from mineralization of the muck soil (Snyder and Jones, 1988). This is consistent with the observation of flooding alleviating the problem since flooding increases Fe solubility and decreases soil NO^3-N concentration.

Dr. Snyder developed a soil test for Fe availability using concentrated hydrochloric acid and suggested that Fe should be applied with soil test Fe index <3.5 (Snyder and Elliott, 1994). A recommendation of 50-150 lb Fe sulfate/acre at planting is suggested in soils with low available Fe. Foliar application was determined to not be effective for post-emergence correction of rice seedling chlorosis.

Other Nutrients:

Nitrogen (N) is a primary nutrient and N fertilizer is generally required on most mineral soils for optimum rice production. In paddy rice in Japan, N uptake by a rice crop was determined to average 60 lb N/acre (Toriyama, 2002). Fertilizer N recommendations for rice grown in Arkansas range from 120 to 150 lb N/acre in 2 split applications (Roberts and Hardke, 2016). However, an estimated 780 lb N/acre is mineralized in drained organic soils in the EAA each year (Terry, 1980). Although the soils in rice production are flooded for most of the crop in Florida, adequate N should be available for the crop.

Phosphorus (P) uptake in rice is estimated at 30 lb P_2O_5/acre (13 lb P/acre) in Florida (Jones et al., 1987), but P removal by rice grain at harvest has been estimated to be 50 lb P_2O_5/acre in Arkansas for a 150 bushel/acre crop (Wilson et al., 2013). In Arkansas, P fertilizer recommendations for rice range up to 60 lb P_2O_5/acre, depending on pH and soil test P. In Louisiana, rice fertilization varies by soil type, with P and potassium (K) fertilizer being required in the coastal prairie and flatwood soils, but not in alluvial clays (Harrell and Saichuk, 2009). On EAA organic soils, P fertilizer trials with rice in the 1980's (Snyder and Jones, 1989) and more recently (2013-2016, unpublished data) have not determined yield increases in response to P fertilization. As determined previously by Snyder and Jones (1989) rice grown in the EAA does not appear to require P fertilizer when grown in rotation with adequately fertilized sugarcane and vegetables.

Potassium uptake in rice is estimated at 82 lb K_2O/acre (68 lb K/acre) in Florida (Jones et al., 1987). Arkansas K fertilizer recommendations range up to 120 lb K_2O/acre depending on soil test K values (Slaton et al., 2013). On mineral soils in Arkansas and other rice-growing areas, strong rice yield responses have been determined to K fertilizer application. However, as with P fertilizer, multiple K fertilizer trials in Florida in the 1980's (Snyder and Jones, 1989) and from 2013 to 2016 have not determined rice yield response to K fertilizer on EAA organic soils. So as with P, generally K fertilizer is not required for rice grown in rotation with adequately fertilized sugarcane and vegetables on EAA organic soils.

There has been a limited amount of research with other nutrients in Florida rice production. In two trials (2014 and 2015) there was no rice yield response to preplant soil applications of manganese (Mn), zinc (Zn), copper (Cu), and boron (B) (unpublished data). These nutrients are routinely applied when sugarcane is planted on EAA organic soils and rice yield response to additional Mn, Zn, Cu, and B is not expected on these soils. Manganese is often limiting in sugarcane grown on high pH soils in the EAA, but flooding increases Mn availability and so the problem should be less in a rice crop when these soils are flooded.

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Insects in Florida Rice

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Introduction:

Insects are a major constraint in the production of rice throughout the world. They are especially severe in tropical Asia and are increasing in importance in Africa and South America. With the continued increases in the human population and losses of arable land, there is an ever increasing need to increase rice production per unit of land through the development of rice production strategies that are sustainable and are economically, environmentally, and socially acceptable. Rice entomologists are playing a major role in the development of sound rice production strategies and will continue to do so in the challenging years ahead (Heinrichs 1994).

Leafhoppers and Planthoppers:

Several species of leafhoppers and planthoppers are serious pests of rice in different areas of the world and frequently occur in numbers large enough to cause complete drying of the crops. In addition to the damage resulting from direct feeding, leafhoppers and planthoppers are vectors of many rice virus diseases. Other than a brief description of leafhoppers and planthoppers in Everglades rice fields by Genung et al. (1979), little was known of the species composition or seasonal population dynamics of leafhoppers and planthoppers occurring in Florida rice, Cherry et al. (1986) determined the relative abundance of leafhoppers (Cicadellidae) and planthoppers (Delphacidae) occurring in southern Florida rice fields.

Leafhoppers (Homoptera: Cicadellidae) and planthoppers (Homoptera: Delphacidae) were collected with sweep nets in southern Florida rice fields during 1983 and 1984. The most abundant leafhopper was *Graminella nigrifrons* (Forbes) and the most abundant planthopper was *Delphacodes propinqua* (Fieber). Total numbers of leafhoppers in rice fields rose quickly after spring plantings and remained relatively constant from May to October. In contrast, individual leafhopper species were more variable in seasonal population trends. *Sogatodes oryzicola* (Muir), a vector of hoja blanca was also detected.

Rice Stink Bugs:

Rice stink bugs cause economic losses in two major ways. Both the adult and nymphal stages feed on individual grains of rice as the panicle develops. With their sucking mouthparts, they can completely remove a grain's content in the milk stage of grain development, thereby reducing yields. More seriously, grains attacked in the dough stage become shriveled kernels with spots varying from light yellow to black. This condition, called "pecky rice" (Fig. 1), has the greatest impact on rice quality and marketability. Research has shown that much of the pecky rice is due to kernel wounding by the feeding behavior of the rice stink bug. This wounding introduces fungi and other microorganisms that cause undesirable discoloration (peck) in the grain.

Fig. 1 "Pecky" rice damaged by stink bug feeding.

Although many different insects can be found in rice fields in Florida, stink bugs are currently considered the most important pest. Jones & Cherry (1986) reported that the rice stink bug, *Oebalus pugnax*, was the dominant species (Fig. 2), comprising more than 95% of the total stink bug population. Cherry et al. (1998) reported that the stink bug *Oebalus ypsilongriseus* was widespread in Florida rice fields. This was the first report of this species being found in commercial rice fields in the United States. Cherry and Nuessly (2010) reported that the stink bug *Oebalus insularis* is now widespread in Florida rice fields. This was the first report of this species being found in commercial rice fields in the United States. The stink bug complex attacking Florida rice is the most diversified and unique stink bug complex in U.S. rice production (Fig. 3).

Fig. 2 Adult common rice stink bug (*Oebalus pugnax*).

Fig 3. Scouting for rice stink bugs with a sweep net.

Rice Water Weevil:

The rice water weevil (Fig. 4) belongs to the family Curculionidae and feeds on a wide variety of plants belonging to the families Poaceae and Cyperaceae. While this weevil is a major pest of commercial rice, researchers believe its original host to be wild rice, *Zizania aquatica* L. The rice water weevil is native to the southeastern United States and was introduced into California rice fields in 1958. The pest was first reported in Florida in 1916 and was noted first occurring on rice grown in Florida in 1979 by Genung et al. (1979). These authors reported the weevil attacking rice at the University of Florida Everglades Research and Education Center at Belle Glade, Florida, and, according to curculionid authority C. W. O'Brien, the species' distribution encompassed the entire state (Cherry et al. 2015).

Fig. 4 Adult rice water weevil.

The distribution of rice water weevil injury (Fig. 5) in rice fields has been shown to vary among different geographic regions. In California, highest populations and most severe injury occur near levee and field margins. Thus, California rice farmers frequently apply insecticides only to these specific areas. However, in the southern United States, including Florida, weevil populations and injury are distributed more uniformly within fields (Way 2003, Cherry et al. 2013).

Fig. 5 Longitudinal scars on leaves caused by feeding of adult rice water weevils.

Registered seed treatments can be applied as preventative control for anticipated economic damage by future weevil populations. Consult your chemical company representative for available seed treatments. In rice water weevil surveys conducted in Florida by Cherry et al. (2016), control measures would have been justified in only 2% of fields sampled. As of now, area-wide infestations of rice water weevil in Florida may not be great enough to recommend the use of seed treatment, but fields may be scouted to ensure that populations do not reach damaging levels.

Manipulating planting date has been suggested as a cultural control tactic for rice water weevils. Early-planted rice has been shown to be less susceptible to yield reductions from weevil feeding and can serve as an important component in a management program. However, other studies have concluded that early planting of rice may in fact increase or have no effect on yield reductions. In Florida, an increase in adult feeding damage was observed as the rice season progressed (Cherry et al. 2016).

In most rice growing regions around the world, rice is grown as a lowland crop where the soil is flooded for a majority of the season. Application of this permanent flood is the most important external influence on the interaction between the rice water weevil and rice (Stout et al. 2002). Reports on the effect of flood depth on rice water weevil populations have been inconsistent. Shang et al. (2004) noted that rice water weevil biology may differ among rice producing areas, and that methods used for management in one region may not apply in another. Cherry et al. (2015) demonstrated that shallow flooding reduced rice water weevil populations in Florida rice but had little to no effect on populations of damselflies (Order: Odonata), leafhoppers (Family: Cicadellidae), spiders (Order: Araneae), or stink bugs (Family: Pentatomidae).

Stem Borers:

Stem borers in the family Crambidae are major insect pests of rice worldwide (Pathak and Khan 1994). Stem borer adults are moths, with females laying eggs on rice plants. Upon eclosion, stem borer larvae feed in leaf sheaths and burrow into culms within a couple of weeks. Larval feeding within culms disrupts plant nutrient movement and panicle development, which can cause incomplete grain filling and whiteheads (killed panicles). Three stem borer species, the sugarcane borer, *Diatraea saccharalis* (F.), rice stalk borer, *Chilo plejadellus* Zincken, and Mexican rice borer, *Eoreuma loftini* (Dyar), infest rice produced in the U.S. Gulf Coast Region (Beuzelin et al. 2016). These three species occur in Florida.

The sugarcane borer, which also infests sugarcane, has a dark brown head capsule and brown dots on the body (Fig. 6). Surveys conducted during the 2017 growing season revealed that this species infests rice at low levels in the EAA. These surveys did not detect infestations of the rice stalk borer.

Fig. 6 Sugarcane borer larva.

The Mexican rice borer (Fig. 7) is a newly detected invasive species in Florida that is a severe pest of rice in Louisiana and Texas. For example, yield losses associated with Mexican rice borer infestations in unprotected rice fields in Louisiana may have exceeded 11% and 29% in 2012 and 2013, respectively (Wilson et al. 2015). Although the insect occurs in central Florida, pheromone trapping has not detected populations in rice fields of the EAA as of August 2017. The Mexican rice borer could threaten rice production in the EAA when it becomes established in the region.

Fig. 7 Mexican rice borer larva (Photo Credit: LSU AgCenter).

Wireworms:

Soil insect data and yield data were obtained from 10 Florida sugarcane fields planted after rice production. Soil insecticides were used at planting for wireworm control except in 12 rows per field which were planted without insecticides. Within each field, one pair of plots was sampled for soil insect populations. Each plot was 20 × 20 meters in size. One plot was selected in an area of the field with soil insecticide and the other plot in an adjacent area without soil insecticide.

Yield data were obtained by two methods. First, stalks per acre were obtained in the summer by counting stalks in six 100 foot sections of row in each area of insecticide application and each area of no insecticide application in each field. Second, stalk weight was obtained in the spring before harvest by weighing four 25 stalk bundles of cane in each area of insecticide application and each area of no insecticide application in each field.

The following data were obtained from these fields from November, 1990 to April 1993. Only one wireworm was found in 100 soil samples (50 insecticide and 50 non-insecticide) taken when sugarcane fields were planted. Since flooding is known to kill wireworms, the extremely low wireworm population present at this time was probably due to the previous flooding of the fields for rice production. There were no significant differences in wireworm populations between insecticide applied and insecticide free areas at 0, 5, 10, or 15 months after planting. Also, there was no significant difference in stalks per acre, weight per stalk, or estimated tons of cane per acre between insecticide applied and insecticide free areas.

In summary, both insect data and yield data indicate that in many cases soil insecticides for wireworm control (Fig. 8) are not necessary when planting sugarcane after rice (Cherry et al. 1994).

Fig. 8 Wireworms are largely killed by rice flooding reducing the later need for soil insecticides.

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Common Diseases in Rice

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1. Bacterial Panicle Blight

Since 2010, this disease has become one of the most important rice diseases in the southern U.S. Bacterial panicle blight is caused by two bacterial pathogens and is now widely distributed throughout Central and South America. The disease was originally reported in Asia, where it was referred to as grain rot. Prior to 2010, this disease was rarely observed in Florida rice production. However, it has since been introduced on infected rice seed.

Causal organisms:

Bacterial panicle blight is caused by two related species of bacteria, *Burkholderia glumae* and *Burkholderia gladioli* (formerly *Pseudomonas glumae* and *P. gladioli*.). They are gram negative rods with three flagella, measure approximately 0.5-0.7 X 1.5-2.5 um, and form white colonies on nutrient agar. They do not fluoresce when grown on King's B medium and they can be selectively cultured on a medium known as 'S-PG medium' developed in 1986.

Symptoms:

Panicle blight is frequently overlooked during early stages of growth but on seedlings it resembles a brown, water-soaked soft rot of the leaf sheath. This may result in wilting. On grain, the infection appears as a light to dark discoloration of the lower glumes following pollination. Affected rice grains may be unevenly distributed on the panicle, although with severe infections, all grains may be discolored. A brown margin may develop between the healthy and infected portions of the grain, and diseased portions of affected grain appear empty. The rachis may remain green up to the seed. The bacterium may cause a rot of the flag leaf sheath with a light center and dark brown border. The disease is manifest primarily as a grain rot and by plant sterility. Frequently, infected panicles may appear more erect or 'upright' than surrounding healthy panicles. In minor infections, the disease may appear as small, isolated foci with severely affected plants surrounded by healthy plants. However, under favorable conditions, these foci may expand and large portions or entire fields may show uniform infection.

Disease cycle:

Panicle blight is primarily a seed-borne disease but the bacteria can survive for periods of time in the soil. A warm temperature disease, panicle blight is favored by extended night time temperatures of over 28 C and day time temperatures of 35 C or higher. The disease is also favored by long rotations of rice after rice, where it builds up in the soil. It is also favored by high nitrogen fertility. Grain yields may be reduced by just a few percent to as high as 50% during severe epidemics.

Disease management:

In Florida, the disease is best managed by planting rice seed that is free of infection. Rice that is planted early is more likely to escape damage due to cooler, less favorable temperatures. Higher disease levels have also been linked to lower potassium levels and excessive nitrogen levels, so these should be adjusted accordingly. Rotations with non-rice crops are also beneficial. Although varietal resistance has been reported, this has not been clearly defined for many U.S. varieties.

2. Brown Spot

Brown spot is a perennial problem in Florida rice production, and worldwide, it trails only rice blast in terms of economic importance. It may occur on both upland and wetland rice and yield losses of 40-90% have been reported in some regions. Impact from the disease may be accentuated in fields that are deficient in nutrients, particularly potassium.

Causal organisms:

Brown spot is caused by the fungal pathogen *Bipolaris oryzae*, formerly known as *Helminthosporium oryzae*. The asexual stage is characterized by conidia (asexual spores) which are obclavate to almost cylindrical, generally slight curved, light to golden brown, with six to 14 crosswalls (septa). Conidia typically measure 14-22 X 63-153 um and may have a hilum (point of attachment on the end) that slightly protrudes. Conidiospores may germinate from one or both ends when provided with sufficient moisture. The asexual stage is considered to be the most important developmental stage epidemiologically, since it repeats throughout the growing season, allowing for disease spread and build-up.

A member of the class Ascomycetes, *B. oryze* may also produce ascomata which are dark brown, globose to elliptical, 360-780 um in diameter, and having a conical to cylindrical beak. Asci or sexual spore sacs produced internally are elongate (21-26 X 140-235 um), cylindrical, and straight to slightly curved. They contain ascospores which are hyaline (clear) to slightly brown, filiform or flagelliform, with 8 to 12 septa or crosswalls. The importance of the sexual stage in the disease cycle is not known.

Symptoms:

Brown spot may attack rice at any stage of development, from the seedling to reproductive stage. On newly emerged seedlings, it may appear as a seedling blight, causing distortion and browning of the coleoptile, primary and secondary leaves. In some cases, it may even infect the root, causing a black discoloration which may stunt or kill infected seedlings.

More frequently however, the disease appears as small brown lesions on the foliage of older plants. Lesions are typically circular to oval and have light brown to gray centers which are surrounded by reddish brown margins. On resistant varieties, the fungus produces only small dark specks, but on moderately susceptible cultivars, lesions are 1 to 4 mm long, and on susceptible cultivars, 5-14 mm long. During severe outbreaks, lesions may coalesce, killing large areas of leaf tissue, turning it necrotic.

Disease cycle:

In temperate regions, infected seeds are considered to be the primary source of inoculum, but the fungus may also survive on infected crop debris. Although a number of closely related grasses are reported as hosts for B. oryzae, their importance in terms of seasonal carryover in Florida has not been investigated. Likewise, the importance of the sexual ascospore stage is also unknown.

Regarding temperature, brown spot has a rather broad infection range. While the optimal range is listed as 20 to 30 C, making it a ‘warm temperature’ disease, the effective range is listed as 16 to 36 c. Free moisture is optimal for spore germination and infection but infection may still occur at relative humidities as low as 89%. Brown spot is most prevalent when the crop is grown in nutrient deficient soils, specifically soils low in potassium, manganese, magnesium, iron, and silica. Such deficiencies are not uncommon on the organic soils of the Everglades Agricultural Area of south Florida. Upland or unflooded rice is also more susceptible to brown spot than flooded rice.

Disease management:

Proper soil nutrition and good water management are critical for the management of brown spot. In areas where these are not easily corrected due to soil pH or shallow soil depth, cultivars with demonstrated resistance to brown spot should be planted. Foliar fungicides, particularly strobilurins and triazoles, have been successful in reducing brown spot severity, but their practicality may be questionable from an economic standpoint.

3. Rice Blast

Blast is probably the most widespread and important disease of rice in the world. It may be highly cultivar dependent, and under favorable conditions, may result in significant yield losses. Rice seedlings or plants at the tillering stage are frequently killed and heavy infections at the panicle stage may result in massive reductions in grain yield. The disease is most severe in rain-fed upland rice and in irrigated rice grown in temperate regions.

Causal organisms:

Rice blast is caused by the fungal pathogen *Pyricularia oryzae,* also known as *Magnaporthae oryzae.* *P. oryzae* is morphologically indistinguishable from another species, *P. grisea*, which routinely infects other grass species, such as St. Augustinegrass. The pathogen is an ascomycete, producing clear (hyaline), fusiform, 4-celled ascospores in unitunicate asci. The sexual stage does not appear to be significant in the spread of the disease. Asexual spores (conidia) are lemon-shaped, tapered on the ends, with two septa or crosswalls. The spores are slightly darkened and translucent, measuring 8-10 um in diameter and 19-25 um in length. Averages are roughly 8.7 X 23.2 um in width and length, respectively. Conidia frequently attach themselves to host tissue by means of an adhesive substance on the apex of the terminal cell. Called “spore tip mucilage”, this glue-like substance adheres to the leaf surface, and the spore germinates shortly thereafter. The fungus then produces an appressorium or penetration peg which punches through the host epidermis. Conidiophores or branches which produce conidia are typically swollen at the base, emerging in clusters from stomates. They are septate, and may range from 60 to 120 um in length. Conidiophores usually give rise to multiple conidia, from one to 20, which are individually supported by very short buds or branches, arising in sequence from the primary stalk.

Symptoms:

Blast symptoms develop on all above-ground parts of the rice plant, but rarely on the leaf sheath or culm. Young leaf lesions are frequently white to light grey-green and have dark green borders. As lesions expand, they become light grey and have necrotic borders. Mature lesions may become diamond in shape or display elongated spindles on the end and develop reddish brown borders. Blast lesions vary in size according to varying levels of host-plant resistance. On more resistant cultivars, lesions may be small necrotic spots, whereas on susceptible cultivars they may be quite large and elongated. Infection at the leaf collar may result in leaf death and severe infections may lead to large patches of dead plants in the field.

Along with lesions on leaf blades, the blast pathogen can infect tiller nodes within the sheath. Internodal infections may also occur. Frequently these infections will result in panicle lodging at or below the neck, resulting in empty or partially-filled florets. Called "blasting', infections can also occur on panicle branches, nodes, and spikelets. The timing of such infections during grain fill determines the amount of yield loss, with early infections occasionally resulting in 100% sterility.

Disease cycle:

Pyricularia oryzae survives on infested crop debris, on seed, and on surviving rice plants. Seedborne inoculum is most important in more temperate regions where there is a rice free period between rice crops. Such is the case in south Florida. Although certain grass weeds have been implicated as a source of inoculum, this source is not usually considered significant. Under favorable climatic conditions, blast may become an explosive disease on a susceptible cultivar. Asexual spores or conidia are easily carried by winds to nearby plants and fields. Leaf wetness is critical for infection and warm days (25-28 C) and cool nights (17-23 C) are optimum temperatures. The influence of temperature on blast may be seen in the length of the latent period, the time between infection by the pathogen until the formation of visible symptoms. The latent period varies from 13 to 18 days at 9 to 11 C, to an optimum of only 4-5 days at 25-28 C. Thus the fungus cycles much more rapidly with warmer temperatures. Although spore production slows as lesions mature, active lesions may support continued sporulation for many days.

Although blast may occur as early as emergence, leaf blast symptoms do not normally develop until tillering, decreasing somewhat as the plant nears panicle initiation. A second period of rapid infection then frequently starts at heading and continues until all tissues have fully matured. Host plant resistance to rice blast has met with both success and failure. With major gene resistance where only one or two genes are involved, control may only be effective for two to three years before those genes are overcome by the pathogen. After this, the cultivar may exhibit high susceptibility to some reduced level of resistance, depending on the situation. More than 85 resistance genes to rice blast have been reported, and all have been overcome by the pathogen at some point.

Quantitative or 'partial' resistance to rice blast has also been reported. Shown to be more durable over time than qualitative resistance, this form of resistance is characterized by fewer and smaller lesions than on susceptible

Disease management:

In Florida, the disease is best managed by planting blast resistant rice cultivars and therefore cultivar selection is one of the most important decisions a rice grower makes. A second important strategy is to establish and maintain a flood as soon as possible. Loss of a flood for any reason greatly enhances susceptibility to this disease.

Proper fertility is also important for managing blast. Avoiding excessive nitrogen and phosphorus applications may help to limit blast development and applications of calcium silicate slag have proven to be beneficial in soils deficient in available silicon.

While fungicides may prove helpful in managing rice blast, timing is very important. A blast fungicide is typically not applied during the vegetative period unless stand is being negatively affected. If blast is present and looking as though it will be significant, an application should be applied at heading. Heading applications should be made when 50-70% of the heads are emerging from the boot. Applications made as little as 5-10 days after this will not be nearly as efficacious. If economics permit, two applications, one at boot to reduce inoculum, and one at heading are more effective than a single application. Scouting for blast is most critical starting at mid-tillering and continuing through heading. Rather than as a cure-all, fungicides should be viewed as only one component of blast management, along with cultivar resistance, proper fertility, and water management.

4. Sheath Blight

Sheath blight, like blast, is one of the most important diseases of rice worldwide. The soil-borne pathogen is capable of infecting multiple host species, surviving in the soil by forming survival structures (sclerotia), or by colonizing plant debris.

Causal organism:

Sheath blight is caused by the fungus *Rhizoctonia solani*, also known by its sexual stage *Thanatephorus cucumeris*. The rice pathogen belongs to anastomosis group AG-1, intraspecific group 1-A. The mycelia of *R. solani* are colorless in young cultures and light yellow to brown in older cultures. The clear or hyaline hyphae are characterized by branching at 45 or 90 degree angles with hyphal branches typically constricted at the point of origin with a septa formed shortly thereafter. Hyphae are multinucleate and range from 8-12 um in diameter. Crosswalls may be observed to have a central hole and are referred to as dolipore septa.

Three specialized types of mycelium are produced: 1) runner hyphae, which have parallel walls and spread rapidly over the sheath and leaf surfaces, 2) lobate hyphae, which produce appressoria or penetration pegs to punch through the host tissues, and 3) moniloid cells, which are short, broad cells formed in short chains to form sclerotia, or survival structures. Sclerotia may vary greatly in size and color, depending upon the fungal isolate. They are white when first formed and turn tan to dark brown with age. Young sclerotia are very dense when first formed and therefore sink in water, however they become buoyant with age as outer layers become vacuolated.

The sexual stage or basidia are barrel shaped and slightly wider than the supporting hyphae, 9 X 14 um in diameter. Sterigmata are long, stout and tapered, and these give rise to basidiospores at their apex. Basidiospores are clear, oblong to ellipsoid, and often have one flattened surface. They average 5.5 X 9 um in size and they are capable of germinating repetitively.

Symptoms:

Although sheath blight occasionally appears on young plants, symptoms usually do not develop until plants are in the late-tillering or internode elongation stage. Initial infections are circular to elliptical, greenish-gray in color, water-soaked lesion near the waterline. The initial lesions are usually about 1 cm in length and enlarge to 2-3 cm in length and 1 cm in diameter over time. Centers become pale green or white, and may be surrounded by reddish to brown borders. Under favorable conditions, the infection spreads by means of runner hyphae to the upper canopy and even laterally to adjacent plants. Lesions on upper plant portions coalesce to cover entire leaf sheaths and stems. Sclerotia may be produced on the plant surface after several days. Loosely attached, these may easily dislodge from the plant once mature and they may initiate additional plant infections.

Infected leaves may sometimes display a banded appearance, caused by repeated growth and progression of the fungus. The pathogen may also infect panicles, reducing grain fill, particularly in the lower portion of the panicle. Entire portions of a field may show infection, with scattered patches or spots of up to a meter in diameter resulting from a single infection. These spots appear as ‘dead zones’ in the field.

Rhizoctonia solani may also cause wilting and death of small seedlings by producing a toxin. Seedling blights can be both pre- and post-emergence.

Disease Cycle:

The pathogen survives between rice crops as sclerotia or mycelium in plant debris. Having a wide host range, *R. solani* may also survive on assorted weed hosts. Sheath blight epidemics are considered to have two phases. In the first monocyclic stage, sclerotia or infective mycelia serve as the primary inoculum and these infect the base of the plant. In the second polycyclic or repeating phase, leaf infections reach the upper canopy and mycelia spread from tiller to tiller and from plant to plant. Spread may occur at temperatures in the range of 23-35 C, with the optimum being 30-32 C. High humidity, above 95%, is also required.

Affected areas may grow in size to exceed 0.5 ha or more under favorable conditions, appearing as large brown patches. While the pathogen may infect the host at any stage from seedling to maturity, disease develops most rapidly during early heading through grain fill. Infection level on the plant is often correlated with the water level, since sclerotia can float and often infect the rice plant at the water surface.

Disease management:

The durability of the *R. solani* sclerotia, its ability to infect a wide range of hosts, and its capability to survive on debris all serve to reduce the effectiveness of crop rotation as a management tool for sheath blight. Rotations with non-hosts long enough to be effective are generally not economically feasible.

Host plant resistance has been investigated with only limited success. In general, cultivars that mature early appear to be more susceptible than later maturing cultivars. Young plants seem less susceptible to sheath blight than older plants, with plants at heading seeming most susceptible. High nitrogen levels and phosphorus levels may increase susceptibility, so balanced nutrition may be important. Silicon may also prove beneficial in reducing sheath blight severity.

For reasons stated above, fungicides have frequently been relied upon for sheath blight management. While strobilurin fungicides have shown good results for sheath blight control, resistance to this group of fungicides has been reported in some areas. If used, a one-time higher rate application at early heading seems to work best and is the most economical.

Production and Post-harvest Processing of Rice

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Introduction:

Rice (*Oryza sativa* L.) is the staple food of about two-thirds of the world's population (Roy et al., 2009). Rice is the single most important food crop in the world for human consumption because it provides 21% of the caloric needs of the world and 76% of that of South-East Asia (Fitzgerald et al., 2009).

Fig. 1 shows a longitudinal section of a rice kernel. Rice is harvested as a covered grain in which the single-seeded fruit (caryopsis) is enclosed in a tough, protective, siliceous hull (husk). The hull is composed of two modified leaves, called the palea and the lemma, that overlap and interlock with each other with the help of two hook-like structures. This interlocking arrangement has been related to the rice grain's resistance to insect infestation (Juliano, 1981) and to fungal damage (Ilag and Juliano, 1982). Inside the hull are three distinct layers of crushed cells that constitute the caryopsis coat; these layers are the pericarp, seed coat, and nucellus. Pigmented rice varieties (like red, purple and black rice) derive their color from the pigments located in the pericarp or in the seed coat. The aleurone layer surrounds the rice grain and the outer side of the embryo; this layer contains almost all of the protein and lipid content of the rice grain. The caryopsis coat and the aleurone layer together are commonly referred to as "bran". Underneath the aleurone layer lies the sub-aleurone layer and the starchy endosperm; rice starch comprises large, polyhedral, compound starch granules that measure 3 µm to 8 µm in diameter (Tester and Karkalas, 2002) which are surrounded by proteinaceous material. The embryo or germ is very small and is located on the ventral side of the base of the kernel. The plumule and radicle are joined by a very short stem called the hypocotyl. It is bound on the outer side by a single layer of endosperm cells, called the sub-aleurone layer, and by the fibrous remains of the pericoat. The endosperm also lines the inner edge of the embryo.

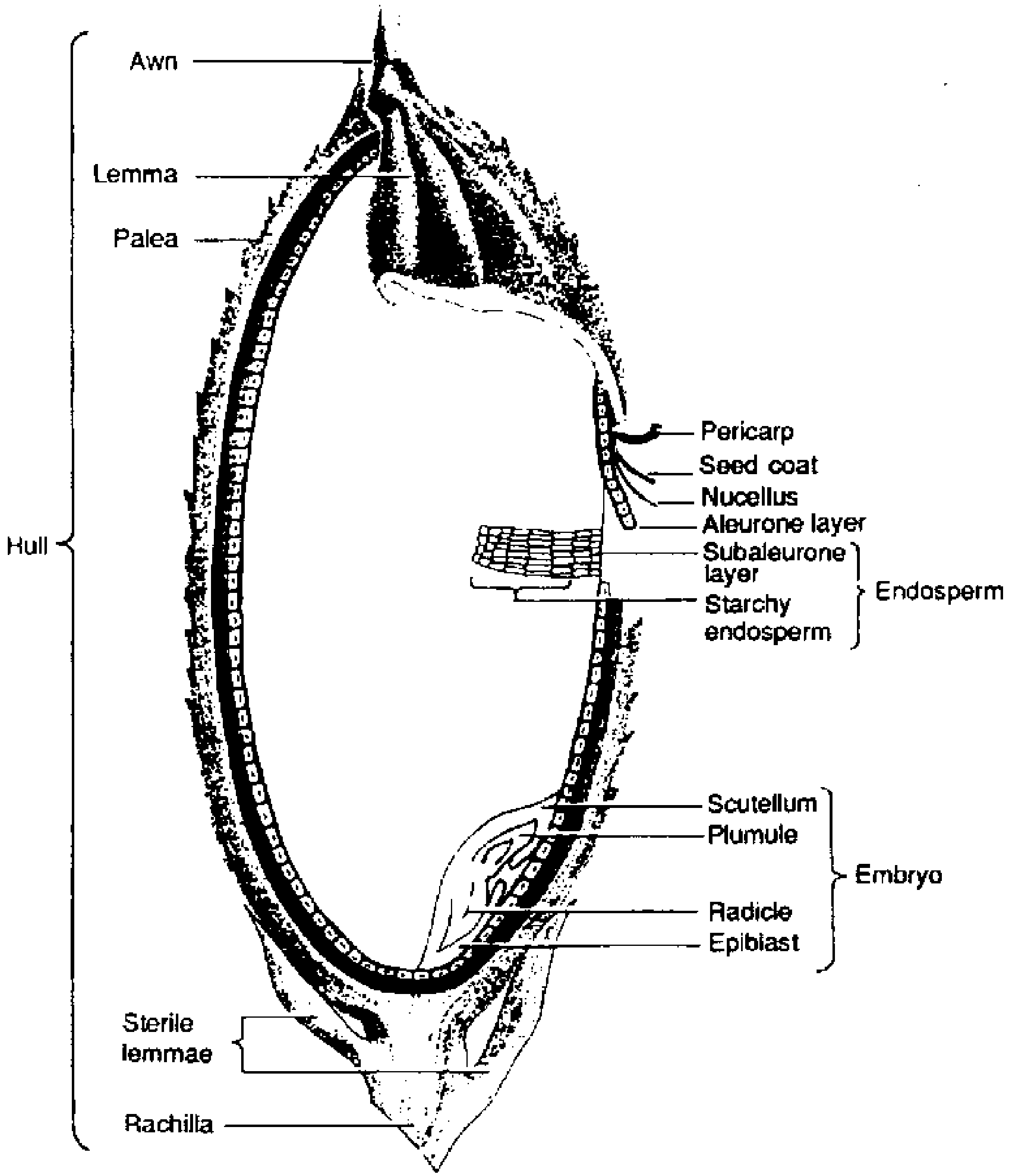


Fig. 1 Longitudinal section of a rice kernel (Adapted from Juliano and Aldama, 1937).

Types of rice:

There are three major “races” of rice in the world: “Indica”, “Japonica” and “tropical Japonica”, or “Javanica”. A “race” is a genetically and often geographically distinct mating group within a species. Indica and Japonica rice are the two major eco-geographical races of *Oryza sativa* L.

Indica is the major type of rice grown in the tropical and sub-tropical regions of the world, viz., central and southern China, India, Pakistan, Java, Sri Lanka, Indonesia, Philippines, and several African countries. Indica rice is characterized by intermediate to tall plants that tiller profusely and have narrow to broad light-green leaves, and its rice grains are slender and flat with awnless spikelets. Indica rice grains have a high amylose content (23% to 31%) and thus, cook drier and non-sticky. Starch, which is major component of the rice kernel endosperm, is made up of amylose and amylopectin. Amylose is the linear polysaccharide made of α-D-glucose units, bonded to each other via α(1, 4)-glycosidic bonds, and has a relatively lower molecular weight. On the other hand, amylopectin is the highly branched polymer of α-glucose units, bonded by α(1, 6)-glycosidic bonds with a much greater molecular weight.

Japonica rice comprises a group of rice varieties that are found in cooler, temperate regions of the world like northern and eastern China, Japan, Korea, Portugal, Spain, and Italy. These have narrow, dark-green leaves, medium-height tillers and short to intermediate plant stature. Japonica rice grains are short and roundish, and vary from awnless to long-awned spikelets. Owing to their relatively low amylose content of 0% to 20%, Japonica grains appear moist and sticky when cooked. The third "race", earlier known as Javanica but now referred to as tropical Japonica, are grown in the high-elevation rice terraces of the Cordillera Mountains of northern Luzon, Philippines, Indonesia, Madagascar and the Americas. Javanica plants are tall with broad, stiff, light-green leaves, and its grains are long, broad, and thick and have relatively low amylose content (0% to 25%).

Although the United States of America (USA) produces approximately only 1.5% of the rice produced in the world, USA's production far exceeds its domestic demand for rice, thus, USA has consistently been the fifth largest exporter of rice, after Thailand, India, Vietnam, and Pakistan, exporting an average of 3.9 mmt per year (on a milled rice basis) over the 2010 - 2017 period (FAOSTAT 2017).

Rice producing regions:

Historically, the four regions that produce most of the US rice crop are: 1) the Arkansas Grand Prairie, 2) the Mississippi Delta (parts of Arkansas, Mississippi, Missouri, and Louisiana), 3) the Gulf Coast (Texas and Southwest Louisiana), and 4) the Sacramento Valley of California. Typically, Arkansas is the leading rice producing state in the USA, often producing nearly half of the total production; in 2016, Arkansas contributed 47.4% (5.4 mmt) of the total US rough rice production of 11.4 mmt (USDA ERS 2016).

Most of the rice grown in California is Japonica while most of the rice grown in the other major rice producing states in the US is tropical Japonica. In fact, each of these four regions in the US generally produce a specific type of rice, long-, medium- and short-grain rice; the grain type is characterized by the length to width ratio of the rough rice kernels. Approximately 70% of the total US production is long-grain rice, which is grown almost exclusively in the Southern US. Medium-grain rice is mainly grown in California, although the Southern US (mainly Arkansas) grows some medium-grain rice. Short-grain rice is grown exclusively in California and accounts for only 1% to 2% of the total US rice production.

Rough rice, often referred to as “paddy”, is the term used for unprocessed rice kernels which have their outer hull/husk and is the form in which rice is harvested from the field. Rough rice is typically harvested at 14% to 22% moisture content (MC) (wet basis) in the Mid-South USA. It is recommended that long-grain cultivars be harvested at 19% to 21% MC and medium-grain cultivars at 22% to 24% MC to maximize “rice milling yield” (Siebenmorgen et al., 2007); this term is explained below. Soon after harvest, the rough rice needs to be dried to approximately 12.5% MC (wet basis) to minimize respiration rates and mold growth (Dillahunty et al., 2000) as well as to inhibit fungi and insect growth (Chen et al., 1997). Dried rough rice is dehulled and then milled for consumption.

Post-harvest processing:

The steps in post-harvest processing of rice and the related terminology is described below. In the US, soon after harvest, rough rice is most commonly dried using commercial or on-farm cross-flow drying systems (Fig. 2) using elevated air temperatures ranging from 104°F to 158°F (Schluterman and Siebenmorgen, 2004; Billiris et al., 2014; Billiris and Siebenmorgen, 2014) to achieve high throughput rates. Cross-flow dryers are so-called owing to the “cross-wise” direction of movement of rough rice relative to that of the heated air; rice flows vertically downwards between two perforated metal screens comprising the grain columns (Fig. 2), while heated air flows through the columns in a direction perpendicular (or “cross”) to that of the rice movement. Typically, ambient air is first forced into the dryer by an axial or centrifugal fan, then heated by a burner using direct combustion of propane or natural gas, before entering the heated-air plenum of the dryer. The height of the drying section in an on-farm cross-flow dryer is typically 12 ft whereas in commercial systems, this height may be as much as 100 ft. Unloading feed-roll augers, located at the bottom of the dryer columns, combine the columns and meter the rice out of the dryer.

Commercial “drying processes” for rough rice typically comprise multiple drying passes, with periods of “tempering”/holding the rice in bins between drying passes. Tempering durations vary largely, and are based upon the experience of dryer operators as well as harvesting and drying logistics. Tempering between drying passes allows intra-kernel material state gradients, which are typically created during heated-air drying, to subside (Perdon et al., 2000; Cnossen and Siebenmorgen, 2000). Because intra-kernel material state gradients are allowed to subside, fissuring and consequent breakage of rice kernels is minimized (Cnossen and Siebenmorgen, 2000; Schluterman and Siebenmorgen, 2007). Tempering also decreases the total drying duration (Aquerreta et al., 2007) by improving the drying rate in subsequent passes (Nishiyama et al., 2006), thereby increasing overall energy efficiency (Calderwood and Webb, 1971; Hwang et al., 2009).

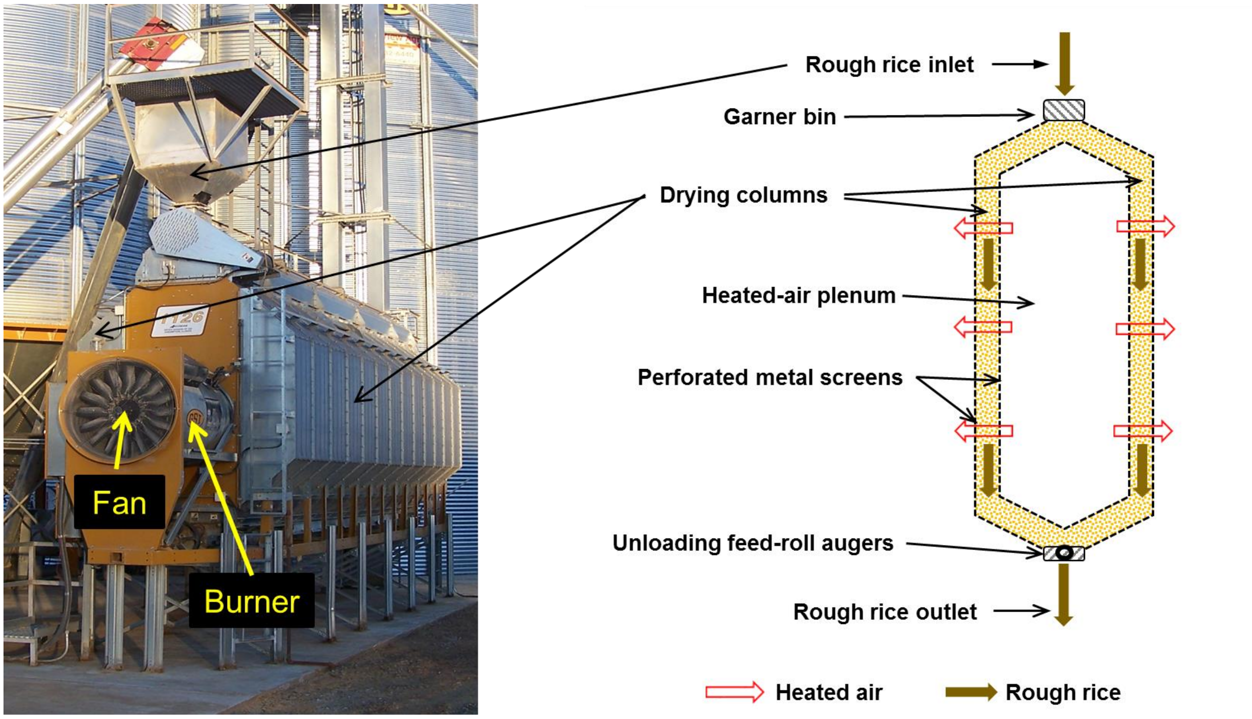


Fig. 2 (Left to right) An on-farm cross-flow dryer (Greg Baltz, Pocahontas, AR) and a schematic of a cross-flow dryer (Prakash et al., 2017).

Once the rough rice is dried to approximately 12.5% MC, rough rice is dehulled to remove the hull to yield “brown rice” (Fig. 3). Rice milling constitutes a series of abrasive and (or) frictional operations that remove the embryo and a specified amount of bran from the brown rice kernels, transforming these kernels into “white rice” or “milled rice”. During milling, invariably some rice kernels break, thus, the milled rice fraction contains “whole, intact” kernels as well as these broken pieces. Then, a series of “grading” equipment are used to separate these intact kernels from the brokens. In rice literature, milled kernels that are at least three-fourths of the original kernel length are called “head rice” (USDA 2009); these are often termed as “whole kernels” or “fancy” in the rice industry (Fig. 4).

“Rice milling yield” refers to either or both the milled rice yield (MRY) and the head rice yield (HRY), defined as the mass of milled rice and head rice, respectively, expressed as a percentage of the original, dried rough rice mass (USDA 2009). Fig. 5 gives the pictorial representation for the calculation of MRY and HRY. A typical milling yield is expressed as “58/70” where the first number, i.e., 58, is the HRY, and the number following it, i.e., 70, is the MRY. The difference of the MRY and the HRY thus quantifies the amount of brokens, i.e., 70 – 58 = 12% brokens.

It is important to understand the steps in rice processing in terms of a mass balance. A 100-lb lot of rough rice yields 80 lb of brown rice since, hulls constitute 20% of the mass of rough rice. Depending on the extent of milling, the amount of milled rice obtained from approximately 80 lb of brown rice differs considerably, yet as a general rule of thumb, about 10% is lost in the bran stream, which includes the embryo and the bran. Thus, typically, 70 lb of milled rice result from dehulling and milling 100 lb of rough rice. Owing to a large number of factors, which include cultivar differences, growing location, growing conditions, drying and tempering operations, storage conditions, milling operations, degree of milling etc., approximately 45 lb to 60 lb "survive" the milling process and is separated from the milled rice mass as "head rice" while the remaining 10 lb to 25 lb become "brokens".

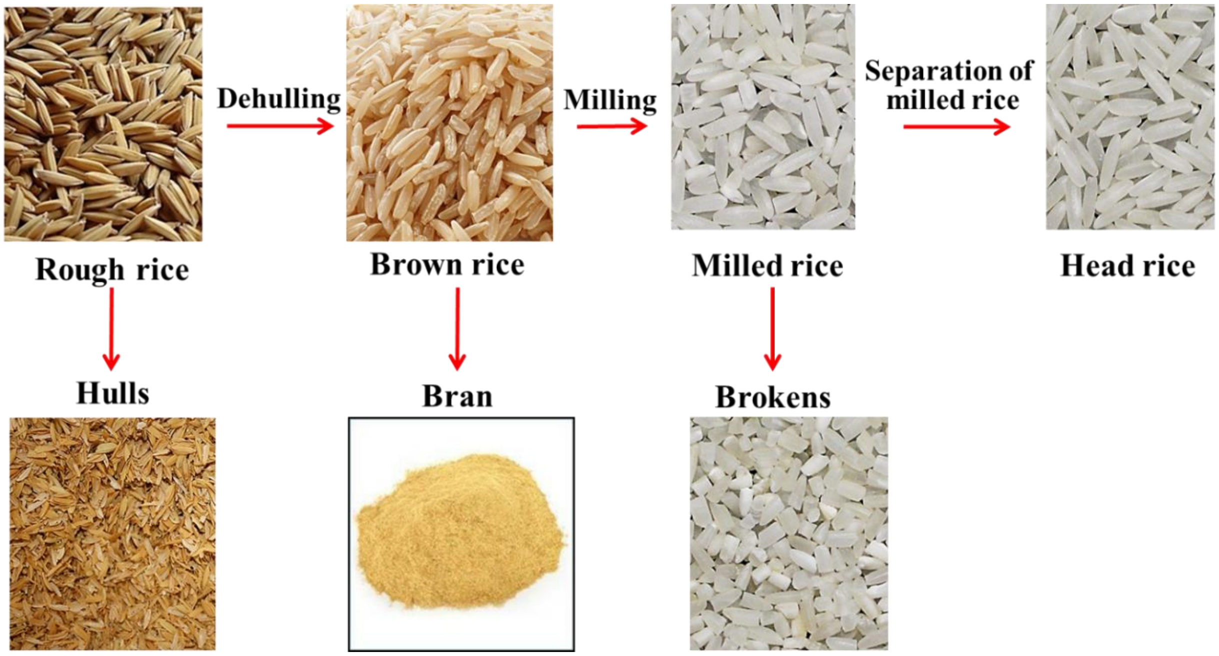


Fig. 3 Steps in the post-harvest processing of rice.

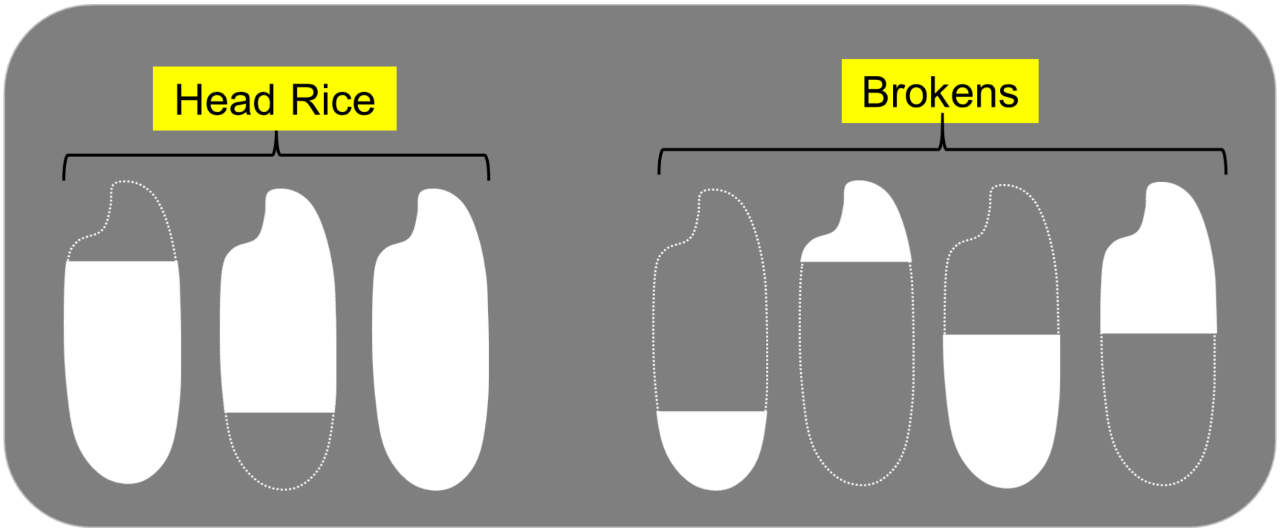
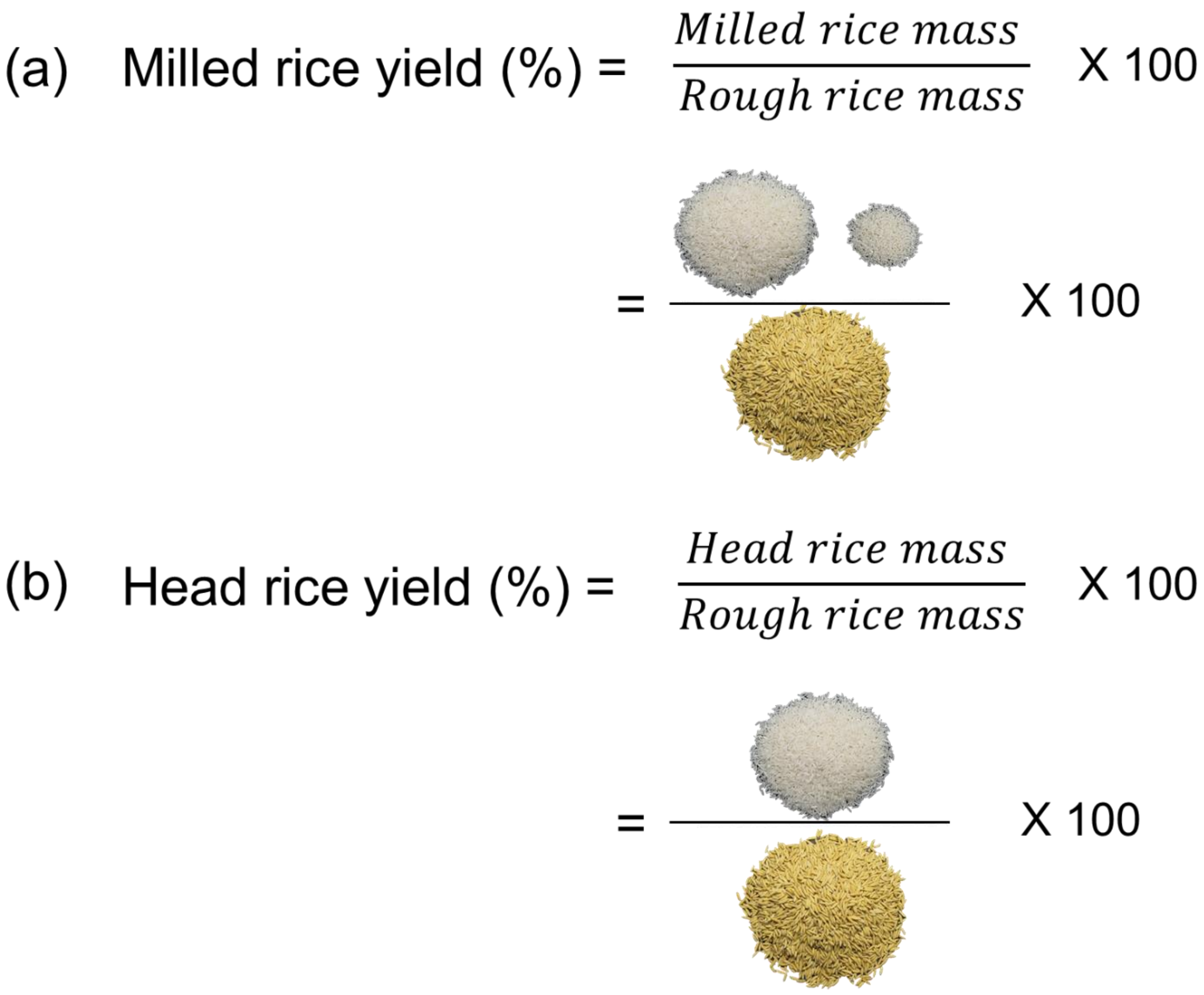


Fig. 4 Schematic showing head rice (kernels that are at least three-fourths of an original kernel length) and broken rice kernels (also called "brokens").



$$\text{(a)}\quad \text{Milled rice yield (\%)} = \frac{Milled\ rice\ mass}{Rough\ rice\ mass} \times 100$$

$$\text{(b)}\quad \text{Head rice yield (\%)} = \frac{Head\ rice\ mass}{Rough\ rice\ mass} \times 100$$

Fig. 5 Pictorial representation for the calculation of (a) milled rice yield, and (b) head rice yield.

Rice is very unique in that unlike other cereal grains, rice is mostly consumed as “table rice” which consists of “milled, intact kernels”, thus, the importance of maintaining the physical integrity of rice kernels cannot be undermined. In most markets, broken kernels are valued at only 50% to 60% that of head rice. Because of the economic importance of head rice relative to broken kernels, the broad objective in rice post-harvest processing and management operations, which include drying, tempering, storage and milling, is to maximize HRY.

Although broken kernels of rice have been typically underutilized in the rice industry, in recent years, the demand for rice brokens has increased considerably. Most of this demand has been due to the increasing number of people being diagnosed with Celiac disease, an auto-immune, genetic disorder of the small intestine (Hartmann et al., 2006; Woodward, 2007), wherein the only treatment for this disease is strict adherence to a gluten-free diet. Rice is naturally gluten-free as well as hypoallergenic, thus, rice is ideal for inclusion in gluten-free diets/formulations. Additionally, brokens are ground into flour; rice flour is used in most baby foods, rice noodles, pasta, cakes, breads and several fermented rice products. Novel uses of rice flour and rice starch include the manufacture of biodegradable and/or edible films and edible cutlery.

Brokens are extensively used in the US pet-food industry; the recent growth in the US pet-food industry serves as a boost for the sale of brokens. Brokens and in fact, even head rice is used for brewing applications. Other co-products of rice processing also find a variety of applications: hulls are used as cattle feed, poultry litter, soil amendment for potting plants, bedding material for plants, for combustion to generate heat for parboiling of rice, and to clean up major oil-spills. Oil is extracted from rice bran to produce rice bran oil, and bran is also mixed with hulls for animal feed.

This is an introductory article on the production and post-harvest processing of rice, the latter includes various steps such as drying, tempering, milling and storage. Since, rice is mainly consumed as an intact grain, the importance of maintaining kernel integrity throughout the various post-harvest processing steps is essential. Other quality attributes for rice are also very important but are beyond the scope of this article. Current post-harvest research efforts are geared towards maximizing HRY while maintaining/improving rice quality attributes, including physiochemical and functional characteristics of rice and(or) rice starch.

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