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Experimentation on Cultivation of Rice Irrigated with a Center Pivot System

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1. Introduction

1.1 Feeding the world

Rice is the staple food for one half of the world's population. Consumed mainly by humans rather than fed to livestock, rice is an efficient food for supplying carbohydrates, vitamins, and nutrients in diets. Demographers predict the Earth's population will increase to nine billion people by 2045 (United Nations, 2004). To keep pace with increased food demand, rice farmers will need higher yields, increased hectares of rice production, and more efficient use of water resources. Unfortunately, traditional rice production uses large amounts of water. Irrigation practices are needed to grow rice with less water and on well-drained soils that are not currently used for traditional flooded rice culture.

Most rice cultivars do not tolerate extended periods of water stress. For optimum yields, rice is produced with irrigation supplied from rivers, lakes, or groundwater aquifers. In the dry-seeded, delayed-flood culture, rice is flooded at approximately the V-4 growth stage (Counce et al., 2000); and the flood is maintained continously until after heading. Insufficient pumping capacitiy sometimes results in dry portions of the fields, leading to nitrogen losses and low yields. Excessive pumping wastes water and energy and increases pressure on levees; furthermore, soil, fertilizers, and pesticides may be carried in the runoff from fields.

1.2 Sprinkler irrigation

This chapter is focused on center pivot sprinkler irrigation systems (Figure 1) for rice production. However, the principles are relavent to other sprinkler equipment such as linear move systems or floppy sprinkler systems with emitters attached to lateral cables stretched between tall poles. Sprinkler irrigation for rice production can be a water-saving alternative to conventional flood irrigation. Although center pivot systems may intially be more costly

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to install, annual labor expenses for rice are reduced because maintaining leeves and gates to control flood water depth is no longer needed.

Fig. 1. Center pivot irrigation system equipped with a backflow prevention valve used to apply irrigation water, and an injection pump for applying liquid nitrogen fertilizer and fungicides for controlling diseases.

Several farmers in the southeast United States conducted field-scale evaluations of rice production with center pivot irrigation in the 1980's. However, most rice growers became discouraged with the system because of management problems. The three main obstacles were (1) diseases, (2) weeds, and (3) ruts from wheels on the outside spans. Since that time, improvements have been made in rice genetics, herbicides, fungicides, and irrigation equipment (Figure 2), which now make it a feasible option for rice production.

Although several scientific studies were conducted with center pivot rice production in the 1980's, there is little recent information available (McCauley, 1990; Westcott and Vines, 1986). Rice research under center pivot systems was started at the University of Missouri-Delta Research Center at Portageville, Missouri in 2008 (Vories et al., 2010). In addition, center pivot manufacturers are working with producers in several countries to demonstrate center pivot rice production and the Missouri team is conducting water use research in South Africa in Limpopo Province. We recently reported on a nitrogen fertigation rice experiment with center pivot irrigation (Rhine et al., 2011) and we are helping several farmers in Missouri grow rice with center pivot irrigation through extension education programs.

In this chapter, we will share our experiences growing under center pivots with regard to rice cultivars and hybrids , herbicide programs and problem weeds, nitrogen fertilization methods, rates, and timing, and chemigation with fungicide to control brown spot and blast diseases. Information will be included for using local weather station data, reference evapotranspiration (ET), and suggest a crop adjustment coefficient for rice to manage irrigation for center pivot rice.

standard two wheels rubber tracks four-wheel drive

Fig. 2. Traction alternatives include (a) standard two-wheel drives, which can create deep ruts and cause the system to stall; the problem is most common on clay soils. For better flotation, (b) tracks can be added or (c) more tires used where high water flow rates occur.

2. Rice cultivars and hybrids

2.1 Asian and African rice

The most widespread rice species grown by farmers are *Oryza sativa* L. and *O. glaberrima.* Cultivation of *O. sativa* began in southern China, Laos, and Thailand (Jones, 2003). Also called "Asian" rice, *O. sativa* is now grown in over 100 countries. Selection and isolation has resulted in indica and japonica subgroups. Generally, indica cultivars have longer grain size and are better adapted to hot climates than japonica cultivars. In Asian countries, India, and the Philippines, *O. sativa* is usually cultivated by transplanting seedlings into flooded paddies. In North, Central, and South America, Europe, Australia, and the Middle East, farmers direct seed rice with a grain drill planter or water seed pre-germinated seed broadcast by airplane.

In countries with rain-fed production, paddy rice can become completely submerged by flash flooding. A few weeks later, rice in the same fields may be subjected to drought stress from lack of rainfall. This is a challenging environment for rice farmers and is not conducive for producing high yields. However, selection has produced rice lines with more drought tolerance than rice from areas with uniform flood culture. Developing rice more tolerant to dry soil conditions would be helpful for reducing short-term water stress. Accessions, such as FR13A, were collected from rain-fed regions that can survive both flooded and dry extremes (Bailey-Serres et al., 2010; Reddy et al., 2010). On the molecular level, the rice lines have an extra ethylene responsive factor called SUB1A which helps them tolerate stress. Marker assisted-breeding was used to develop a "near isogenic SUB1 introgression line" of a high-yielding japonica inbred rice cultivar, M202 (Fukao et al., 2011). Survival rates of M202 (SUB1) plants were higher, compared to the parent line without SUB1. Plants from both groups were exposed to both submergence and low soil moisture. Currently, it is not known whether this is just a survival mechanism or if SUB1 will help rice plants produce higher yields by tolerating short-term water stress. Marker-assisted breeding technologies will play an important role in helping scientists improve rice tolerance to dry soil conditions. Marker assisted breeding can be done without "genetic engineering" since in most cases, a natural marker can be found without using transgenes. The process saves breeders time and increases accuracy by providing an effective screening test for desired genes on progeny after a cross is made.

Cultivars with *O. glaberrima* (sometimes called "African rice") in their pedigree are generally more tolerant of low soil moisture conditions than *O. sativa*. Deepwater and upland ecotypes of *O. glaberrima* are grown in West Africa (Mclean et al., 2002). Deepwater African rice cultivars are produced in flooded river basins and deltas. Upland African rice is usually grown in rainfed culture. When adequate irrigation is available, Asian rice cultivars generally have greater yield potential than African rice, but, in non-irrigated rice fields in West Africa, Asian rice is more susceptible to drought stress, soil nematodes, insects, and viruses. Monty Jones, co-recipient of the World Food Prize of 2004, cross-bred *O. sativa* and *O. glaberrima* to produce interspecific hybrids. Several challenges were overcome including "sexual incompatibility and hybrid sterility" (Sarla and Swamy, 2005). One of the goals was to combine the yield potential and grain quality of Asian rice with the pest and drought resistance of African rice. The Africa Rice Center (formerly WARDA) releases interspecific hybrids called "Nerica" (Figure 4), which were produced by crossing the two species.

Fig. 3. Nerica rice cultivar from the Africa Rice Center grown with center pivot irrigation in Limpopo Province, South Africa.

2.2 Rice cultivars and diseases

Rice plants are stronger and less susceptible to diseases when adequate water and nutrients are available. An effective disease control program for sprinkler irrigated rice begins with selecting cultivars or hybrids with the greatest disease resistance. The program should include regular field scouting for diseases and the option to apply fungicides, preferably by chemigation.

The most devastating disease to rice in North America is blast [*Pyricularia grisea* (Cooke) Sacc.]. Blast is spread by airborne spores. The severity of blast in a region varies greatly from year to year due to weather conditions. Crop rotation is an important control practice because the fungus can survive on straw residue from the previous year. When highly susceptible cultivars are grown with flood irrigation, plant pathologists recommend maintaining a deep flood (>10 cm, *Rice Production Handbook,* 2001). Since sprinkler irrigation is not flooded, of course, this is not possible. Blast disease was common in many Mid-South United States rice fields in 2009 (Figure 4, Table 1).

Fig. 4. In 2009, blast infection on 'Francis' cultivar with no fungicide applied resulted in complete crop loss under center pivot irrigation at Portageville, Missouri.

Center pivot irrigated rice planted with moderately resistant cultivars such as Templeton (Lee, 2009) combined with fungicide chemigation was effective in controlling the disease. Currently, there are no commercial cultivars in the United States that are 100% resistant to the disease. Crop rotation and straw management between growing seasons helps control the disease, but blast can mutate to a different race and cause serious injury to a previously resistant rice cultivar. Therefore, it is important that fields be scouted closely and fungicide applications made before the disease becomes severe.

Some debate exists among farmers on how to best manage sprinkler irrigation on rice in the presence of a fungal disease. Should more or less water be applied? Keeping rice leaves wet with frequent irrigations could intensify the problem. However, brown spot disease, (*Bipolaris oryzae*, Breda de Haan Shoemaker), in particular, tends to flare up when rice is stressed from lack of soil water. Reducing irrigation could actually increase the disease. Water-stress from lack of water makes rice plants more susceptible to diseases than plants with adequate soil moisture. In Missouri in 2008 center pivot trials, brown spot disease occurred on susceptible rice cultivars (e.g., 'Wells') when we failed to maintain soil moisture tensions below 50 centibars. Wells and Francis were the only cultivars out of six tested where we observed brown spot disease. After applying fungicide by chemigation and increasing the irrigation amount, the brown spots were not found on new growth upper leaves.

Rice cultivar	No fungicide	Fungicide applied
	---------------------------kg rice grain ha^{-1}-----------------------	
Templeton	7,950	8,335
Cocodrie	5,550	8,000
Taggart	5,400	7,880
Francis	0	7,345
Wells	850	7,220
Catahoula	7,350	5,990

Table 1. Rough rice grain yields in 2009 (high blast environment) from cultivars with and without azoxystobin fungicide applied by chemigation through the center pivot system.

Shealth blight (*Rhizoctonia solani*, Kuhn) is less likely to be a problem with center pivot than flood irrigation (A. Wrather, personal communication). Although brown spot and blast may increase with center pivot irrigated rice, the incidence of sheath blight diminishes in this cropping system. In flood irrigated rice, the soil borne fungus moves in the water and attacks the rice stems. Without a flood, we have not found shealth blight in rice.

2.3 Hybrid rice

In flood irrigated trials across the southeastern United States, rice hybrids averaged 17 to 20% higher yields than inbred cultivars (Walker et al., 2008). Hybrid rice lines usually produce more tillers and have greater blast resistance than inbred rice cultivars under center pivot irrigation. In a high blast disease environment, hybrids can also respond to fungicide applications. Planted in the same field as inbreds in 2009 (see Table 1), RiceTec CLXL729 yielded 8,300 kg ha^{-1} without fungicide and 9,950 kg ha^{-1} with fungicide.

Hybrids are better suited for sprinkler irrigation than inbreds because of their vigorous root growth. If a sprinkler irrigation application is delayed, rice hybrids are less likely to show leaf curling. However, hybrid seeds tend to cost more per bag than inbreds. Some of this cost is offset by the lower seeding rate. Because rice hybrids produce more tillers per seed than inbreds, fewer seeds per hectare are needed. Typically, hybrid seed is drill planted at 28 to 34 kg ha^{-1} versus inbred seed planted at 100 kg ha^{-1}.

Making two 45° angle drill passes at one-half rates helps avoid gaps in the plant canopy, although most growers may not want to spend the extra planting time. The low seeding rate for hybrids makes plant population uniformity especially critical. Scout the field shortly after emergence to assess the stand. If a field has a history of bird damage, applying a bird repellent to the seeds before planting is a good prevention measure. Early in the season, a thin plant population makes weed control more difficult. Fortunately, by mid-season, the robust tillering of hybrids helps them fill in the open areas. If there any large skips in the field, replant those areas as soon as possible for better weed control. Uneven stands make weed control difficult later, especially in fields irrigated by center pivot systems. In conventional rice culture, flooding prevents water stress and suppresses many weeds. A complete crop canopy helps control weeds since any place in a field there is not a rice plant growing to shade the soil, weeds will emerge and grow.

Fig. 5. Seeding rate for inbred rice cultivars is usually 60 to 70% higher than hybrid rice.

3. Irrigation management

3.1 Flood versus sprinkler

Most types of rice do not tolerate low soil moisture even for short periods of time. For rice grown under center pivot irrigation, this is a special concern since there is not a paddy full of water to act as a buffer. Depending on the pumping capacity and irrigation rate, large pivot systems can require more than two days to complete a revolution. If the soils have low water holding capacities, such as low organic matter sandy soils, rice plants are more likely to become stressed between water applications. Also, irrigation systems in humid regions are often under-designed assuming some rainfall will occur. With these systems in a dry growing season, farmers cannot keep up with evapotranspiration (ET, the combined water loss from soil and plants) demand of the crop.

No reports were found in the literature for side-by-side comparisons of water use between flood irrigated and center pivot irrigated rice. Burt et al. (2000) found the potential irrigation application efficiency for continuous flood irrigation is 80% under practical conditions, which is within the range they reported for center pivot systems (75 - 90%). However, they added that surface irrigation systems "require the most ‘art‘ of all the irrigation methods, both to obtain a high distribution uniformity and a high application efficiency. In general, people have not learned the art." In practice, large quantities of water can be lost from fields using surface irrigation, including continuous flood.

Rice farmers experience less-than-optimal flood irrigation application efficiencies for many reasons. Leaky levees and sandy areas that do not retain flood water are common problems. In the United States, farming operations are typically spread over large areas, requiring farmers to simultaneously manage numerous irrigation systems at different locations. One worker is often responsible for managing pumps in several fields, requiring him/her to move from field to field to determine when to begin water application and return to the field to determine if the irrigation is complete and shut off the water supply. Each field waters differently and often differences are observed within fields due to factors like highly variable soils. Farmers often produce multiple crops, so they may be harvesting wheat and planting double-crop soybeans at the same time they are applying the initial flood to their rice.

With flood irrigation in the US Mid-South, rice requires considerably more water than other crops (Hogan et al., 2007). In Arkansas, the Rice Production Handbook reported typical values for the amount of irrigation water applied to rice on Arkansas soils ranged from 610 to 1220 mm (Tacker et al., 2001). Similarly, Vories et al. (2006) reported a range of 460 to 1435 mm observed for 33 Arkansas rice fields during the 2003 through 2005 growing seasons and Smith et al. (2006) reported values from 382 to 1034 mm in Mississippi in 2003 and 2004. Even at the low end of the Handbook range (610 mm), rice production in Arkansas over the ten years from 2000 through 2009, based on harvested cropland hectares from USDA-NASS (2010), required an average of 3.6 billion m^3 of irrigation water per year.

The large amount of water applied to flooded rice has resulted in two problems: the energy costs associated with pumping make up a significant portion of the rice production budget, and the cost is greatly influenced by fluctuations in energy prices; and water shortages are being observed in some rice-producing areas. The US Army Corps of Engineers (2000) reported that by 1915, only about a decade after commercial rice farming began in parts of Arkansas, the main alluvial aquifer was already being tapped at a rate that exceeded its ability to recharge in some areas. The aquifer serves as the principal water source for agriculture in eastern Arkansas and surrounding areas, and similar problems have been encountered with some surface water sources in the region.

Reducing the water requirements for rice has been a goal of farmers and researchers for many years. Vories et al. (2005) reported that a multiple inlet approach required 24% less irrigation water than conventional flooding and the method has been widely adopted. Producing rice in a row-crop culture with furrow irrigation rather than with continuous flood was also investigated. Vories et al. (2002) compared furrow irrigation of rice with conventional flooding and reported consistently lower yields. Studies during the 1980s addressed sprinkler irrigation of rice in Louisiana (Westcott and Vines, 1986) and Texas (McCauley, 1990) and reported large yield reductions compared with flooded production. Producers will not readily abandon flooded production for an alternative system that produces lower yields. However, more recently, Vories et al. (2010) reported comparable yields between center-pivot irrigated and flooded rice on a producer's field in Arkansas.

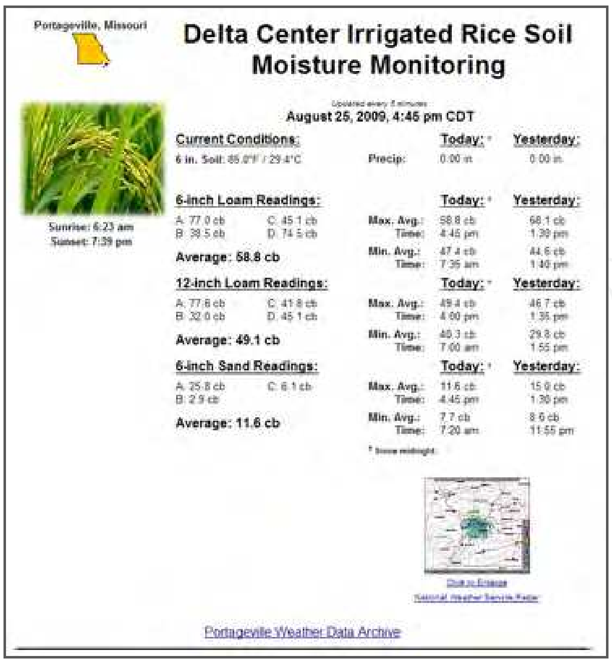
3.2 Center pivot irrigation field tests

In response to renewed interest in center pivot rice, the University of Missouri and USDA-ARS began to investigate center pivot irrigation of rice in Portageville in 2008. The project was in conjunction with the Missouri Department of Natural Resources and Valmont Irrigation, Valley, Nebraska.

Much of Southeast Missouri farmland has abundant groundwater near the soil surface. For rice farmers in this region, the advantages of center pivot rice production are less about water savings than being able to grow rice in fields that do not hold flood water. Producers are looking for additional options in crop choice on fields not suited to flood irrigation and ways to cut energy costs for pumping. In 1811-1812 A.D., four earthquakes occurred in the Mid-South United States exceeding 8 on the Richter scale. The events shattered the alluvial plains between the St. Francis River and the Mississippi River, extending south of New Madrid, Missouri, to Marked Tree, Arkansas. During the quakes, sand was extruded from the water-saturated subsoil and flowed upward in geysers to the surface forming sand blows. The impacted counties in Northeast Arkansas and Southeast Missouri are now part of a major rice producing region of the United States, but farmers must be cautious when selecting fields to produce rice because some fields in do not hold flood water very well. Freeland et al. (2008) discussed sand blows and fissures, which are similar to sand blows but linear in nature, and despite land grading efforts by farmers, these features still persist in fields and affect the abilities of soils to hold flood irrigation water for rice production.

Rainfall in the Mid-South United States is sufficient for rainfed crop production, but periods of drought during the growing season make irrigation essential for optimum yields of all widely produced summer crops. Furthermore, climate change is expected to increase the frequency and severity of drought in the region. However, irrigation scheduling, the correct timing of irrigation during the growing season, is more difficult in sub-humid regions like the Mid-South than in arid locations. Factors such as cloudy weather, rainfall, and temperature swings caused by the movement of weather fronts all complicate irrigation scheduling. Weather conditions in sub-humid regions vary greatly from year to year and even within a year and the variability must be accounted for in the scheduling system. Most commonly used methods either measure or estimate soil water content. Although many types of instruments have been developed to measure soil water content, using many different kinds of technology, all have drawbacks. In addition, the highly variable soils in the region have limited the use of soil water measurements for irrigation scheduling.

In our first series of experiments, we focused on nitrogen management and the typical irrigation schedule was 12 mm of irrigation water applied every other day unless rainfall occurred. WaterMark ® (Irrometer, Co., Inc., Riverside, CA) soil moisture sensors were used to help manage irrigation water applications (Figure 6). The sensors were installed at depths of 15 and 30 cm below the soil surface and buried wires from each sensor were connected to a central datalogger that transmitted the data by radio to a server and the internet. Dr. John Travlos and Greg Rotert at the University of Missouri developed an alert system which notified us by email and cell phone when average soil water potential dropped below -50 centibars (Figure 7). The system functioned satisfactorily, but sensor to sensor readings were variable, partly due to differences in the soil profile among the sensor locations.



(c) internet website for soil sensor readings

datalogger and transmitter

soil moisture sensor glued to PVC pipe

Fig. 6. WaterMark soil sensor (a), datalogger and transmitter (b), and webpage (c) displaying soil moisture updated every 5 minute intervals.

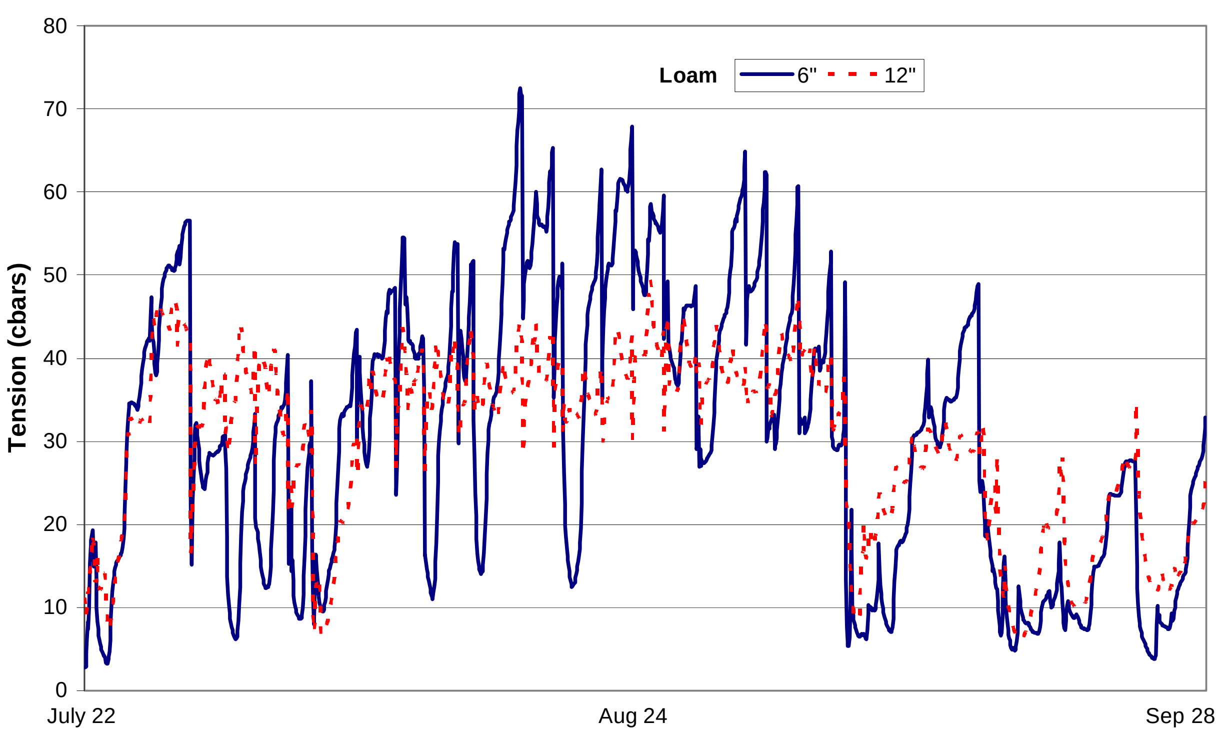


Fig. 7. Soil water tension on silt loam soil under center pivot irrigation in 2009 at Portageville, Missouri.

3.3 Water balance models

If crop water use estimates are available, daily soil water in the rooting zone can be tracked from the beginning of the growing season until harvest. *Soil water deficit* is the difference between the amount of water that is currently in a soil and the amount needed to fill the root zone back up to capacity (called *field capacity* or *well drained upper limit*). It pays to keep a balance sheet for soil water deficits, similar to a checkbook registry where rainfall and irrigation amounts are added and crop water use is subtracted, to determine when and how much to irrigate. Some farmers adjust water rate each time they irrigate and have a fixed schedule (e.g. twice a week). Others keep the same irrigation rate and vary the length of time between irrigations. The amount of water roots take up from soil between rainfalls or irrigations is affected by soil texture and rooting depth. As soils become drier, roots are not able to pull as much of the remaining water from the films surrounding soil particles. Generally, fine soil particles hold water tighter than coarse particles and the allowable soil water deficit to attain high yield varies between clays, loams, and sandy soils. Roots cannot grow as deep on soils with compacted layers called “pans” and allowable deficits must also account for this. Growers should record rainfall near their fields. Weather station measurements of solar radiation (sunlight), air temperature, humidity, and wind speed can be used to estimate a reference ET. ET from weather station data is typically referenced to a short grass (ET_o) or tall grass (ET_r) and is converted to ET for the specific crop (ET_c) by multiplying by an adjustment factor called a *crop coefficient*. Most methods that estimate soil water content rely on a crop coefficient to relate ET_c to a reference evapotranspiration at different growth stages. Allen et al., (1998) presented procedures for estimating crop coefficients.

The University of Missouri recently completed a web based ET advisory system for maize, soybean, rice and cotton (Fig 8) . A link to the site can be found at http://agebb.missouri.edu/ weather/ realtime/portageville.asp. Local farmers can access the information on portable computers or cell phones with internet access, allowing farmers to make decisions in the field about irrigation timing and rates by comparing weekly rainfall versus crop water use.

Crop coefficient values change during the season based on crop growth stage (Figure 9). The short-grass-reference coefficient curve shown in Figure 9 is experimental and is being evaluated in field trials in Missouri and South Africa. Heat units (Degree Day 50’s) are used to predict rice growth stages for the x-axis. During early vegetative growth stages, the crop adjustment factor increases linearly, which increases the calculated daily ET_c. After the crop reaches about 80% canopy coverage, the adjustment curve flattens, but daily ET_c still varies based on temperature, cloudiness, humidity level and wind speed fluctuations. After a rain or irrigation when rice plants are small, reference ET_o may be a better estimate of total ET in the field due to increased evaporation from the wet soil and plants. Daily ET_o values are available on each University of Missouri real-time weather station website.

To schedule high frequency irrigation with systems such as center pivots, Allen et al. (1998) recommended using seperate coefficients for estimating crop transpiration and soil evaporation. In this system, a basal crop coefficient (K_{cb}) describes plant transpiration and a soil water evaporation coefficient (K_e) describes evaporation from the soil surface. The Arkansas Irrigation Scheduler (AIS; Cahoon et al, 1990) uses a dual crop coefficient approach to calculate a water balance to use in scheduling irrigation. Rooting depth is not used explicitly in the program, but is implicit in the choice of a maximum allowable SWD or management allowed depletion (MAD). Cahoon et al. (1990) provided a detailed description of the program and Vories et al. (2009) provided information about changes to the program since the earlier publication, including allowing the user to input a locally determined ET_o. However, since US rice is almost always produced with flood irrigation, much less work has been devoted to irrigation scheduling for rice than for other crops.

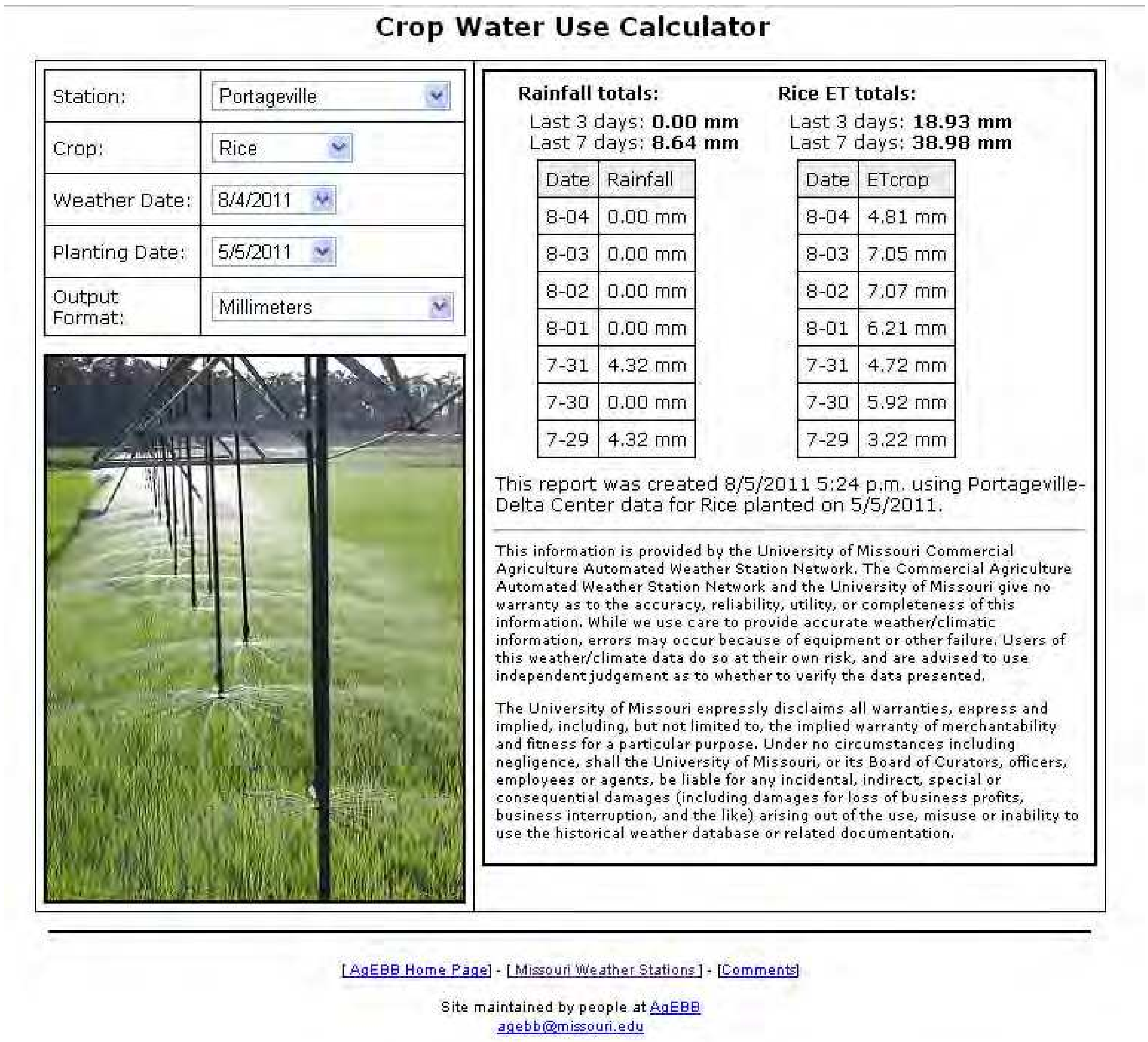


Fig. 8. Output from Missouri Crop Water Use program accessed by smart phone.

When tracking soil water deficits, use common sense to decide how many inches or millimeters to credit rainfall in the balance sheet. "Effective" rainfall amounts can be less than the total recorded by the weather station. Farmers may have a good idea of how much rain is lost to runoff water from a particular field, but runoff is affected by duration and intensity of the rain storm, soil properties such as texture, structure, initial water content, and slope, and vegetative and residue cover. Runoff is most likely when a large amount of rainfall occurs in a short time period or when the soil was already saturated before the rain started. Reduce the rainfall entered as a credit based on your estimate of water staying in the field.

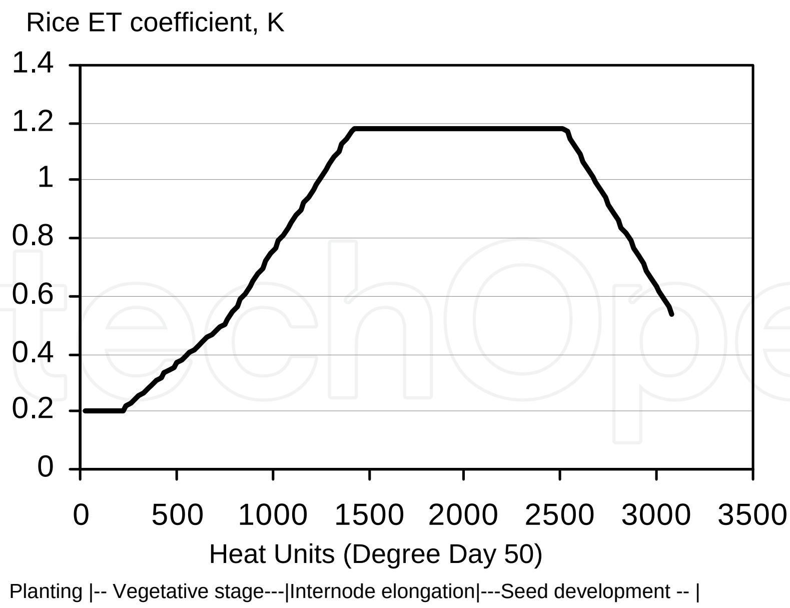


Fig. 9. Experimental rice evapotranspiration adjustment coefficient (K).

4. Weed control

The most difficult part of growing rice without flooding for most farmers is weed control. In 2008, blackbirds fed on seeds after planting. The reduced plant stand made weed control more difficult later. As the surviving seedling grew, tillers helped fill in the plant skips, but in places where there were gaps in the canopy, new weeds continued to emerge all season and as a result we had to hand weed to keep the field clean. In 2009 and 2010, we treated seed with a bird repellant and planted the rice seed 1 cm deeper to inhibit bird feeding.

4.1 Herbicides

Herbicides are used in traditional flood irrigated drill seeded rice, but the suppression effect provided by flooding is a major component of rice weed control. The goal of farmers with center pivot irrigated rice should be to start with a clean field, spray weeds while they are still small (Figure 10), and manage the crop to acheive a solid rice canopy as soon as possible, similar to producing other non-flooded crops. The biggest challenge in 2008, our first year growing rice under center pivot irrigation, was controlling palmer amaranth (pigweed; *Amaranthus palmeri*, S. Wats.). We conducted weed control studies using conventional herbicides and Clearfield technology. Clearfield technology uses imazethapyr and imazamox herbicide resistant rice cultivars (not genetically engineered). When Newpath® (imazethapyr) herbicide was sprayed early in the season, we found that pigweed in the field were not killed because they were resistant to ALS (acetlactate synthase) herbicides. The pigweed apparently became ALS resistant when imazaquin (Scepter®) was repeatedly sprayed on soybean in the field in the 1990's.

Clearfield technology works well in fields without ALS resistance. Fortunately, we were able to develop an alternative program using clomazone, propanil, quinclorac, halosulfuron, acifluorfen, and bentazon. Spray timings are very critical for weed control and a successful program was clomazone pre-emergence followed by applications of propanil and quinclorac when the pigweeds were in the 2 to 4 leaf stage (Table 2). Our last herbicide treatment of the season was acifluorfen/bentazon applied to control any weeds not killed just prior to crop canopy closure.

Fig. 10. The key to maintaining weed control in rice is starting with a uniform plant population and spraying weeds while they are still small.

Weeds will be different at every location. In South Africa, our major weeds were wandering jew (*Tradescantia fluminensis*, Vell.) and wild watermelon (*Citrullus lanatus*, Thunb).

Application timing Weed stage	Herbicide‡	USD cost/hectare
Preemergence	clomazone	$28.75
2-4 leaf †	propanil + quinclorac + halosulfuron	$127.00
4-5 leaf	propanil + quinclorac	$84.57
4-5 leaf	acifluorfen + bentazon	$24.85
Total		$265.17

† Leaf growth stages were from palmer amaranth pigweed.
‡ Trade names for herbicides are clomazone (Command), propanil (Stam), quinclorac (Facet), halosulfuron (Permit), and acifluorfen + bentazon (Storm). Mention of trade names should not be considered an endorsement of these products by the University of Missouri.

Table 2. Herbicides and costs per hectare for chemicals applied in non-weed control test areas under the center pivot irrigated rice at Portageville, MO in 2009.

Of course, weed control in center pivot rice depends on having good herbicides and rice herbicide availability is an issue in some African countries. Center pivot irrigation may give farmers the opportunity to plant rice in countries where it has never been produced on a large scale. While this is great, it can create short-term logistical problems for farmers purchasing rice herbicides. It is a "chicken and egg" scenario in that until chemical companies see a potential for future returns from large rice plantings, they will not apply for herbicide labels, but farmers cannot start growing rice without the herbicides. If governments want to promote rice production in their countries, procedures should be made to allow easier experimental use testing of standard rice herbicide such as propanil and quinclorac which have been safely used in other countries for decades.

5. Nitrogen fertilization and timing

Nitrogen in flood irrigated rice systems is usually applied as granular urea (46 % N) by ground spreader equipment early in the season and supplemented by airplane after fields are flooded. The average cost of applying N by airplane in Missouri is about $7 per 45 kg of fertilizer. In center pivot irrigated rice, fertigation using an injection pump is an option for splitting total N into several applications (Figure 11). Injection pump equipment can also be used for fungicide chemigation for blast to save additional aerial application costs. In flood irrigated fields, dividing total N from urea into several split applications usually does not increase rice yields unless there is a problem maintaining flooded conditions. In Missouri experiments with furrow- irrigated rice on sandy loam soils, splitting total N into three applications produced significantly higher yields than a single application (Hefner and Tracy, 1991). However, in Arkansas, applying additional N on furrow-irrigated rice with clay soil after R0 growth stage did not increase yields (Vories et al., 2002).

Most of the research reports for rice nitrogen management are from flooded culture. Extension recommendations for total N rates in flood irrigated rice fields are based on empirical N field tests and adjustments made for specific cultivars, crop rotation, and soil texture. Rice farmers using delayed flood irrigation sometimes split total nitrogen (N) between two or three N applications. The first urea N application is made at V4 growth stage on dry soils followed immediately with a permanent flood. The goal is to push the urea below the soil surface with irrigation water and maintain a consistent 2 to 4 inch flood depth until the field is drained before harvest. Without oxygen, soil bacteria do not convert ammonium from urea to nitrate. Denitrification occurs mainly in rice fields when inconsistent flooding causes alternating aerobic and anaerobic soil conditions. Midseason N at R0 growth stage applied via airplane is beneficial for increasing rice yield when there is a problem maintaining floodwater from levee leaks or sandy areas in fields.

Two rice cultivars and one hybrid were grown from 2008 to 2010 at Portageville, Missouri under center pivot irrigation. Plots were fertilized with urea (46 % N) broadcasted at V4 growth stage, followed by five weekly applications of liquid urea – ammonium nitrate (UAN, 32 % N) applied to simulate fertigation. Total N rates were 0, 50, 101, 151, 202 and 252 kg N ha^{-1} with 50% of total N from urea/50% from UAN or 25% of N from urea/75% from UAN. An interaction was found for yield between total N and rice genetics (cultivars and hybrids). Economic optimum N rates for most cultivars and hybrids were from 124 to 168 kg N ha^{-1}. When 151 kg total N ha^{-1} was applied, hybrid rice produced 5,167 to 10,156 kg ha^{-1} while cultivars produced 3,648 to 9,110 kg ha^{-1} (Table 3). In 2009 and 2010, 151 kg total N kg^{-1} yielded significantly more grain when 75% of N was applied as UAN fertigations compared to 50% as UAN. However, for most total N rates, application programs did not make a significant difference in yield. For percent milled head rice, an interaction was found between year and rice genetics. However, head rice was not affected by nitrogen management.

Cultivar/hybrid	Total N	2009	2010
	kg N ha^{-1}	-----------kg rice ha^{-1}-----	
Templeton	0	6,527	4,876
	50	8,045	5,393
	101	7,031	3,648
	151	9,110	5,827
	202	9,242	6,760
	252	8,020	6,514
RT CLXL729	0	7,812	4,385
	50	9,249	6,759
	101	9,387	7,465
	151	10,156	5,167
	202	10,092	7,056
	252	10,263	4,448

Table 3. Rice yields from center pivot irrigated research plots with different total nitrogen rates averaged across fertigation timing treatments at Portageville, Missouri.

For Missouri fields rotated with soybean, a recommended program for center pivot rice is 35 kg N ha^{-1} broadcast at first tiller growth stage followed by five weekly fertigtion applications at 22 kg N ha^{-1}. For the first tiller application, 17.5 kg N as urea and 17.5 kg N as ammonium sulfate are blended and broadcast dry. In tests on flood irrigated rice, the S in ammonium sulfate promotes early tillering and more leaves to shade weeds. Boron at (0.8 kg ha^{-1}) is usually added to the blend to prevent B deficiency. The most common liquid fertilizer for fertigation is UAN (32%N). If the field was planted in a non-legume grass crop such as corn or rice, an additional sixth fertigation application of 22 kg N ha^{-1} is recommended.

6. Fertigation and chemigation

Acheiving good mixing of fertilizer or fungicide with irrigation water is critical to making uniform fertigation and chemigation applications. In South Africa, we injected ASN liquid fertilizer (ammonium sulfate nitrate) at the base of the main vertical pivot pipe without an atomizer (e.g., Mister Mist'r®) inserted in the injection port. The atomizer helps to spread the fertilizer in the irrigation stream, which is especially important when there is a short mixing length. Based on the size and green color of the rice, most of the nitrogen was applied in the nearest span to the pivot point. Liquid fertilizer is heavier than water and tends to flow on the bottom of the main pipe and may not have gone past the first span. To prevent this from happening, use of an atomizer and injecting at a port on the water supply pipe that will get the most turbulence before flowing up the pivot point (Figure 11 a) is highly recommended.

Other equipment required for fertigation are a backflow prevention valve, hoses, a chemical storage tank and injection pumps. A backflow prevention valve is necessary to prevent accidental chemical contamination of the irrigation water source (lake, river, well, etc.). Some atomizers come with an internal mechanical spring for a two way check valve to prevent water from the irrigation system from flowing into the chemical supply tank. If not part of the atomizer, a separate check valve is needed to prevent a fertilizer or chemical spill in case of a system malfunction.

Each year in the N experiment, azoxystrobin fungicide was applied through the center pivot irrigation system using an injection pump at R2 and R4 growth stages (Figure 12).

(a) Backflow prevention valve, chemical diffuser, and hose from injection pump

(b) Liquid supply tank for fertilizer or fungicide used for chemigation

Fig. 11. Essential equipment required for chemigation or fertigation for center pivot irrigated rice.

Two types of injection pumps, piston and diaphragm, are available for chemigation and fertigation (Figure 13). Piston type injection pumps are often more difficult to change rate settings but after they are calibrated, they provide very accurate delivery. Be sure the injection pump can be calibrated to match the rate per hectare and size of the field. If an endgun will be used be sure to include that area in the calculations and realize that the system flowrate will vary depending on the endgun status. If you have a pump that is not accurate at low rates for fungicide, it may be possible to dilute the chemical in water in the chemical supply tank to acheive the desire rate of active ingredient per hectare.

7. Insect control

Most of the insects that can attack flood irrigated rice will have the same or perhaps more severe impact in center pivot irrigated rice. The Missouri Rice Degree Day 50 program (http://agebb.missouri.edu/rice/ricemodel.htm) shows when to scout for specific insects and pesticide control options in rice.

Insect pressure was light in Missouri center pivot rice from 2008 to 2011. We sprayed one time for fall armyworm (*Spodoptera frugiperda*, J.E. Smith) control but rice farmers were also spraying flooded fields in the region for the pest at the same time. We are concerned that billbugs (*Sphenophorus* spp.) could be a problem in the future. Insecticide seed treatment is used to prevent billbugs from multiplying on young rice. We found several billbug larvae, tiny white worms, feeding on lower stems and roots late in the 2011 season in a field in continous rice since 2009 (Figure 13a). We have not found any grape colaspis (*Colaspis brunnea,* Fabricius) but based on their behavior in flood irrigated rice, we suspect they might be a potential problem in center pivot irrigated rice.

Fig. 12. Two types of injection pumps commonly used for chemigation. The pump on the left is a piston type and the pump on the right is a diaphragm type.

In South Africa, spotted maize beetle (*Astylus atromaculatus*, Blanchard) migrated in large numbers to the center pivot rice field from maize fields that had finished pollination (Figure 13b). The beetle mainly feeds on plant pollen. It generally is not an economic concern in maize because the abundance of maize pollen in the air. In maize, the tassel (male flower) is seperate from the ear and silks (female flower). But in rice the male and female are together and the majority of plants are self-pollinated. The cutting and chewing of the rice flowers by the spotted beetles to get the pollen appeared to cause sterility in some of the rice plants in our field. More research will need to be done to determine the economic impact of these beetles on center pivot rice.

8. Soil compaction

In flooded rice, a soil "traffic pan" is not a problem because water is readily available to the plant. But, in center pivot irrigated rice, compaction which prevents root growth to lower soil layers makes rice plants more prone to water stress between irrigations. Wet soils are especially vulnerable to soil compaction from heavy equipment. We are currently measuring soil compaction in a center pivot irrigation timing test in Missouri to determine the relationship between soil compaction and rice yields in different areas of the field.

(a) billbug larvae on rice roots

(b) spotted beetle on maize tassel

Fig. 13. (a) Billbug larve feeding on roots and lower stem of center pivot rice in Missouri and (b) spotted beetles migrated from neighboring maize field to center pivot irrigation rice in South Africa.

9. Conclusions

As the world population increases more rice for food will be needed. Center pivot sprinkler irrigation is a viable method for producing rice, particularly in fields that are not suited for flood irrigation. Irrigation scheduling based on ET or soil moisture sensors is recommended to avoid excessive or inadequate applications of water and produce optimum yields. Selecting rice cultivars and hybrids with disease resistance and making timely application of chemicals for pest control are critical for producing a successful crop.

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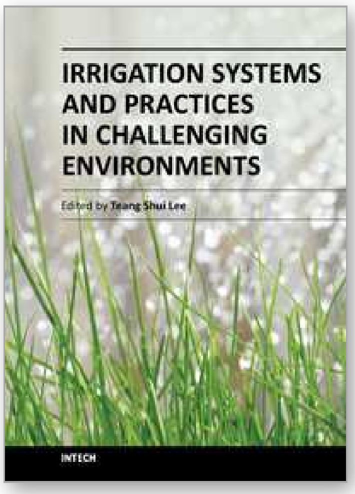

Irrigation Systems and Practices in Challenging Environments
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The book Irrigation Systems and Practices in Challenging Environments is divided into two interesting sections, with the first section titled Agricultural Water Productivity in Stressed Environments, which consists of nine chapters technically crafted by experts in their own right in their fields of expertise. Topics range from effects of irrigation on the physiology of plants, deficit irrigation practices and the genetic manipulation, to creating drought tolerant variety and a host of interesting topics to cater for the those interested in the plant water soil atmosphere relationships and agronomic practices relevant in many challenging environments, more so with the onslaught of global warming, climate change and the accompanying agro-meteorological impacts. The second section, with eight chapters, deals with systems of irrigation practices around the world, covering different climate zones apart from showing casing practices for sustainable irrigation practices and more efficient ways of conveying irrigation waters - the life blood of agriculture, undoubtedly the most important sector in the world.