Chapter 5

Rice Production with Furrow Irrigation in the Mississippi River Delta Region of the USA

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Additional information is available at the end of the chapter

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Abstract

Furrow irrigated rice is an alternative method for growing rice with less water and labor than conventional flood irrigation. In the Mississippi River Delta region, layflat plastic pipe is used to supply water to furrows from irrigation wells. Different size holes are punched in pipe to optimize uniformity of water distribution. Beds are made before planting to channel water down furrows. Rice seed is planted in rows with a grain drill. Water infiltration in furrows is two-dimensional through a wetted perimeter with soil in the bottom of furrows and sidewalls of beds. An ideal field for furrow irrigation has no more than 0.1% slope with high clay content. No rice cultivars have been developed specifically for furrow irrigation but tests showed that some cultivars tolerate water stress better than others. In field trials, rice yields with furrow irrigation were lower than flooded rice with the greatest yield loss in the upper part of fields. However, results indicated that rice yields can be increased with proper timing of nitrogen fertilization and irrigation and adaption of new rice herbicides for weed control.

Keywords: irrigation, furrow, beds, layflat pipe, scheduling

1. Introduction

Farmers have grown rice in flooded fields for thousands of years. To survive in waterlogged soils, rice plants developed a unique plant structure. Within hours of submergence, rice plants produce aerenchyma cells to form air tubes in the stems which helps move oxygen internally from above the water to the roots [1]. This mechanism gives rice a competitive advantage over weeds that cannot survive in water. However, in the absence of flood water, rice plants lose this advantage with weeds and are not able to tolerate long periods of time without irrigation or rainfall. Rice is less suited for aerobic soil conditions than other summer grain crops such as maize and sorghum.

In environments where water is in short supply or pumping costs are high, producing rice with furrow irrigation saves water and fuel compared to flood irrigation. In the Mississippi River Delta Region of the United States, the main reason farmers grow furrow irrigated rice to avoid the labor needed to install and remove levees and gates [2]. This region includes the states of Louisiana, Arkansas, Missouri, Tennessee, and Mississippi. Furrow and center pivot irrigated rice grain usually has low arsenic content. In flooded soil, iron is reduced by anaerobic conditions releasing soluble arsenic for rice roots to uptake. Research in Arkansas and Missouri showed significantly less arsenic in the harvested grain from sprinkler and furrow irrigated rice compared to flooded rice [3–5].

No rice cultivars have been released by breeders developed specifically for furrow irrigation. Farmers need to plant cultivars with the best possible disease resistance. Asian rice (*Oryza sativa*) is divided into five groups: indica, aus, tropical japonica, temperate japonica, and aromatic [6]. The majority of rice cultivars grown in Mississippi River Delta are long-grain types selected with high amylose content for indica cooking properties. Cultivars grown here are mainly indica type but also may have one or more japonica parents in their pedigree [7]. Hybrid rice is often made by crossing indica and japonica parents which provides high heterosis vigor in offspring [8, 9]. Rice breeders typically select for progeny with increased yield potential and resistance to sheath blight [*Rhizoctonia solani* (Kuhn)] and blast [*Pyricularia grisea* (Cavara)] diseases [10, 11]. Blast which spread by wind borne spores is the main concern of farmers growing furrow irrigated rice. Sheath blight is spread by floating spores in flood water which does not apply to furrow irrigation. Blast control practices such as planting cultivars rated with good resistance or applying fungicides is not always enough to prevent the disease [12]. In flooded rice, blast disease is most severe in water stressed plants growing on top of levees or the highest part of a field where water is shallow. Blast can also be devastating in aerobic rice grown without flooding. Where rainfall and irrigation water are scarce, farmers need rice varieties to plant with improved drought tolerance and ability to resist diseases [13].

Approximately 40 million hectares of rice is grown in places around the world where water resources are limited [14]. Upland rice (*Oryza glaberrima*) grown in rainfed fields of sub-Sahara Africa are generally more tolerance to drought conditions than Asian rice. Using embryo rescue techniques, crosses were made between *O. sativa* and African upland (aerobic rainfed) rice (*O. glaberrima*) by scientists at the West Africa Rice Development Association [15]. These crossbred varieties are widely grown in Africa. However, when sufficient water is available either by irrigation or abundant rainfall, these cultivars often produce lower yields than their parent Asian rice lines.

Much effort has been placed in Asian countries on identifying genes in *O. sativa* rice responsible for tolerance to abiotic stresses such as high sodium and low soil moisture conditions [16–18]. Lee et al. [19] increased rice grain yields by 23–42% in drought stress conditions with plants overexpressing root specific OsERF71 compared to controls.

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2. Row beds, field slope and soil texture

Before planting furrow irrigated rice, beds are made in fields to channel the flow of irrigation water in furrows down the slope in the field. Farmers typically use lister or disk hipper equipment pulled with tractors to make the beds in the fall. Winter rains firm the soil and melt soil clods into beds. Beds should be tall enough at rice planting to prevent irrigation water from breaking over bed tops. Sometimes, in place of beds, farmers can plant on flat soil and use furrow plows which cuts evenly spaced narrow trenches for water to flow. The optimum spacing of the water furrows depends on the lateral wicking or soaking properties of the soil. A common bed spacing is 76 cm (30 inch). Rice is planted parallel with beds using a grain drill in 19 cm (7.5 inch) row spacings. Depending on row spacing, water in furrows come in direct with only 20 percent of the soil in a field compared to complete soil coverage in conventional flood irrigated rice [20].

Rice plants on the tops of beds are the first to become water stressed and most prone to die in high evapotranspiration (ET) weather conditions. Water infiltration in furrow is two-dimensional through a wetted perimeter with soil in the bottom of furrows and sidewalls of beds. Rice plants growing near the center of beds are the farthest from furrow water. Clay soils have smaller pores between individual particles than sand or silt. This causes clay soils to more effectively wick furrow irrigation water through small capillary pores across beds than loam soils (**Figure 1**). Capillary rise is the ability of water to flow in narrow spaces in opposition to gravity [21]. This is the action that allows paper towels to soak up liquid spills.

An ideal field for rice production with furrow irrigation is precision graded using lasers with no more than 0.1% slope with high clay content. For rice, a tail levee should be constructed after planting and stand establishment. This will save water and maintain near-flooded conditions in the low end of the field. At some point, a farmer will rotate rice to other crops such as soybean to disrupt disease and insect cycles. Soybeans require adequate surface drainage to avoid waterlogging and damaging roots [22]. Other crops usually need at least 0.10 to 0.15% slope to grow well. Most soils cannot adequately soak across beds for rice when slopes are greater than 0.2% because water flows too fast down the furrows. If the slope is not uniform, water pools in low areas and flows across beds.

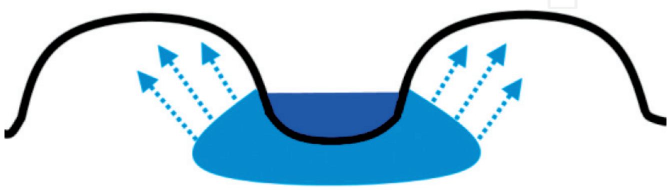

Figure 1. Irrigation water infiltrates into soil below the furrow and wicks to each side and up into beds by capillary rise against gravity through small soil pores.

3. Layflat irrigation pipe

In the past, farmers used rigid aluminum pipe to apply furrow irrigation to crops in the Delta Region. Around 1990, rigid pipe began to be replaced by flexible, plastic layflat pipe [23]. The tubing is usually white in color and sold in large rolls. Generally, the thicker the mil of the plastic, the greater the pressure a pipe can handle without bursting. Most farmers use 6 or 10 mil thickness. A common type is 30 cm (12 inch) diameter, 10 mil thickness and rolls out to 402 m (1/4 mi) length. It costs around $275 USD. It will handle up to 3785 liters per minute (1000 gallons per minute) and 90 millibars (1.3 pounds per square inch) pressure [24]. Layflat pipe is usually installed with a "polypipe roller" implement which is mounted on the three point hitch of a tractor. One end of the tubing is attached to a well pipe with nylon zip ties and duct tape (**Figure 2**). The tractor moves slowly across the end of the beds on the high end of the field. The roller has a small plow which cuts a groove in the soil and the layflat pipe is rolled out in the trench. The shallow trench help keep the tubing from shifting when irrigation water is pumped into it. It is best to install layflat pipe on a calm day to avoid empty pipe from blowing away before it can be filled with water. After the pipe has water in it, wind is usually not a problem.

The well should be started and water pumped into the pipe as soon as possible. After water reaches the open end of the pipe, a knot is tied in it. As water pressure increases in the pipe, holes are quickly punched in the plastic pipe at every furrow to avoid letting the pipe explode. To obtain even water flow across the field, small holes are punched near the well where pressure is highest. Hole sizes should be made progressively larger going away from the well. Computer programs such as PHAUCET developed by USDA-Natural Resources Conservation Service can be used to determine the optimum hole sizes to punch at each furrow [25]. In large fields, it may be difficult to maintain enough pressure in long runs of plastic pipe. To solve the problem, fields can be divided in sections with pipe gates opened and closed to irrigate one area at a time or in equal blocks in a split-set configuration using a programmable surge valve [26]. Irrigation with surge valves is usually done in two stages (**Figure 3**). The first stage

Figure 2. Connecting plastic tubing to well pipe with zip ties and duct tape.

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Figure 3. Surge valve used to improve distribution of furrow irrigation in fields.

advances water in furrows across the field in the shortest possible time. The second stage cycles water sets to improve infiltration in soil on the upper end of a field. A tail levee helps avoid losing water to runoff. Since the crop is rice, flooding the lower end of a field is not a problem unless it becomes more than .

Linquist et al. [3] found that the reproductive stages of rice are the most sensitive to water stress. Alternating wetting and drying by irrigation in rice vegetative stages did not reduce yields if flooding was maintained from panicle initiation through harvest. In treatments where wetting and drying cycles was done the entire season methane emissions were reduced 93% compared to continuous flooded rice.

4. Irrigation scheduling

Rice is less forgiving than other crops when irrigation water is applied too late or in insufficient amounts. Most irrigation decisions by farmers are made by looking at the crops or soil. A national survey showed that 44% of farmers scheduled irrigation on fields based on visual condition of the crop and 25% checked the feel of the soil [27]. Only 3% used daily crop evapotranspiration (ET) and 3% used soil moisture sensors. Three percent of the farmers said they began irrigating when they saw their neighbor start.

Irrigation scheduling programs are useful tools for improving water efficiency in furrow irrigated rice. Several state extension services have developed mobile phone apps linked to electronic weather station networks to calculate evapotranspiration (ET) used for irrigation scheduling [28–31]. Obtaining daily data is a challenge for farms located outside weather station networks. In a two year study, we compared electronic atmometers (ETgages) to weather stations [32]. The ETgages showed good accuracy at 1/10 the cost of a station for supplying daily ET estimates.

Most state extension irrigation apps use the same algorithms to calculate daily soil water balances. The complex calculations are not displayed to users in most irrigation apps. The Penman-Monteith equation is usually used to estimate standardized short-grass evapotranspiration called ETo. The first version was developed in 1948 by Howard Penman and other engineers have fine-tuned it over the years [33]. ET is the combination of transpiration from the crop and evaporation of the water from the soil or plant surfaces. The University of Missouri Extension Service maintains an agricultural weather station network (mesonet) which provides weather data to farmers for managing irrigation. The weather stations must meet standards approved by the American Society of Agricultural Engineers [34]. Most of the 34 stations in the mesonet have a Campbell Scientific™ CR-1000 data logger which is programmed to calculate standardized short-grass evapotranspiration called ETo. For farmers calculating daily crop ET for irrigation scheduling, ETo is multiplied by a coefficient (Kc) specific to the crop in the field. In the Northern Hemisphere, ETo is usually highest in June, and July when days are longer. ETo varies from year to year which is a limitation for irrigation scheduling from printed charts that rely on long-term weather averages.

Farmers do not have time to manually calculate daily crop ET and soil water deficits from weather data for their fields. The main difference between extension irrigation apps is their interface design and ease of use. Growers usually just want to know which fields on their farm need irrigation today or the coming week. Predictions such as crop growth from temperature are important but secondary. In 2015, the University of Missouri Extension Service released an irrigation app for mobile phones called the Crop Water Use app which uses daily ETo from the state mesonet [31]. Many of the equations in the Missouri program including crop coefficients were modified from the Arkansas Irrigation Scheduler. A crop coefficient for non-flooded rice was made working with scientists at University of Arkansas and USDA-Agricultural Research Service [35].

Irrigation frequency is impacted by the app setup settings by the farmer. In the Missouri program, soil available water holding capacity, rooting depth and percent allowable depletion determine the irrigation trigger. Fields with sandy soils with low available water holding capacity trigger faster and need smaller amounts of irrigation water more frequently than medium textured soils. In a field trial with furrow rice on silt loam soil, we found that setting the rooting depth at 30 cm (12 inches) in the app produced the highest grain yields in 2017 (**Table 1**). A possible explanation for the significantly lower yields with the 15 cm root setting

Rooting depth trigger	Irrigations	Total water in season	Rice yield†
cm	number	cm	Mg ha^{-1}
15	15	76	8.98 c
30	11	55	9.68 a
45	7	36	9.36 b

†Yield values followed by the same letter were not significantly different at the 0.05 level.

Table 1. Irrigation applications and rice yields for three root depth triggers in the crop water use app for furrow irrigated rice at the Missouri Rice research farm in Qulin, Missouri in 2017.

Field location	Rice yield†
	Mg ha^{-1}
upper	8.61 c
middle	9.32 b
lower	10.09 a

†Yield values followed by the same letter were not significantly different at the 0.05 level.

Table 2. Rice yields from three locations in furrow irrigated field averaged across irrigation trigger treatments at the Missouri Rice research farm in Qulin, Missouri in 2017.

is that more nitrogen was lost by denitrification compared to treatments with less water. Averaged across irrigation trigger treatments, the lowest yield occurred in the upper parts of the test field. The lower part of the field had standing water part of the time because of water held back by the end leeve (**Table 2**).

5. Nitrogen management

Prior to the last decade, most farmers in the Mississippi River Delta region split nitrogen fertilizer between two or three applications in the season on flood irrigated rice [36]. A typical program was 100 kg N ha^{-1} applied immediately before flooding at the 5 leaf stage and 34 kg N ha^{-1} applied at internode elongation (IE) followed by 34 kg N ha^{-1} two weeks later. Now many farmers apply all the nitrogen before flooding. In 2017, a nitrogen test was conducted to evaluate timing nitrogen applications on furrow irrigated rice at four stages of growth. Total nitrogen ranged from 100 to 250 kg N ha^{-1} (**Table 3**). Results showed that

	Application timing					
Treatment	5-leaf stage (5 L)	Internode Elongation (IE)	IE + 2 weeks	Boot	Total N	Rice yield†
	kg N ha^{-1}					Mg ha^{-1}
1	50	50	0	0	100	8.99 c
2	50	50	50	0	150	9.47 b
3	50	50	0	50	150	8.90 c
4	50	50	50	50	200	9.86 a
5	100	50	0	0	150	9.15 c
6	100	50	50	0	200	9.69 ab
7	100	50	0	50	200	9.06 c
8	100	50	50	50	250	9.62 ab

†Yield values followed by the same letter were not significantly different at the 0.05 level.

Table 3. Rice yields from nitrogen treatments at 5-leaf, internode elongation (IE), IE + 2 weeks, and boot growth stage at the Missouri Rice research farm in Qulin, Missouri in 2017.

IE +2 weeks	Rice yield†
kg N ha^{-1}	Mg ha^{-1}
0	8.61 c
50	9.32 b

†Yield values followed by the same letter were not significantly different at the 0.05 level.

Table 4. Rice yields from nitrogen treatments at internode elongation (IE) + 2 weeks averaged across applications at other growth stages at the Missouri Rice research farm in Qulin, Missouri in 2017.

N timing	p Value
5 L	0.4484
IE + 2WK	<0.0001
5 L*IE + 2WK	0.4127
BT	0.7357
5 L*BT	0.2687
IE + 2WK*BT	0.2478
5 L*IE + 2WK*BT	0.2715

5 L = 5 leaf stage, IE = internode elongation, 2WK = 2 weeks, BT = boot growth stage.

Table 5. Analysis of variance for effect of nitrogen treatment on rice yield at the Missouri Rice research farm in Qulin, Missouri in 2017.

treatments that included 50 kg N ha^{-1} applied two weeks after IE produced more rice than other treatments (**Tables 4** and **5**).

6. Rice cultivar and hybrid evaluation

A evaluation of rice cultivars and hybrids was conducted in 2017 in adjacent Missouri fields furrow and flood irrigated. Each line was randomized and replicated in each field. In every case, rice yields were higher in flooded plots compared to furrow irrigated plots (**Table 6**).

	Irrigation method			
Cultivar	**Furrow**	**Flood**	**Difference**	
	Mg ha^{-1}			%
RTXP760	10.43	11.59	1.16	11
CL153	7.51	8.77	1.26	17
RT7311 CL	10.89	12.40	1.51	14
CL XL745	9.83	11.64	1.81	18

	Irrigation method			
Cultivar	**Furrow**	**Flood**	**Difference**	
	Mg ha^{-1}			**%**
Diamond	9.73	11.69	1.97	20
CL272	7.31	9.32	2.02	28
Roy J	8.42	10.58	2.17	26
LaKast	8.27	10.48	2.22	27
MM17	6.15	9.22	3.07	50
Jupiter	8.01	11.89	3.88	48

Permission to publish results was granted by MOARK Agricultural Research, LLC.

Table 6. Rice yields from cultivars grown with furrow and flood irrigation at the Missouri Rice research farm in Qulin, Missouri in 2017 (source: Nathan Goldschmidt).

However, two hybrids exceeded yields of 10 Mg ha^{-1} in furrow irrigated rice with less than 15% reduction in yield compared to flood.

7. Weed control

Weed control programs for center pivot irrigated rice were discussed in an open access book chapter by Stevens (2015). Similar weed problems occur in furrow irrigated rice. The goal with all non-flooded rice is to maintain good weed control until the plants develops enough leaf canopy to shade emerging weeds.

Often a difficult weed to control in non-flooded rice in the Mississippi River Delta is palmer amaranth pigweed (*Amaranthus palmeri*). In most fields, clomazone applied preemergence and propanil + quinclorac + halosulfuron applied when pigweed reach 2–4 leaf stage works well. If more pigweeds emerge later, another application of propanil + quinclorace or acifluorfen + bentazon can be made.

For many years, chemical companies did not released any new herbicides to control weeds in rice. Recently, saflufenacil (Sharpen™), an inhibitor of protoporphyrinogen oxidase (PPO inhibitor) was labeled by BASF to apply on rice postemergence before panicle initiation. In Missouri trials, Sharpen was effective for weed control but caused significant leaf burn at one location. Additionally, with the advent of PPO resistant Palmer amaranth, this herbicide may become obsolete.

A new broad spectrum arylpicolinate rice herbicide named Loyant™ (florpyrauxifen-benzyl) was released by DOW Chemical Company from a new class of chemicals after EPA approval in 2017. Missouri trials in 2015 showed that it might be a "game changer" for pigweed control and a good fit for non-flooded rice. A test in 2016 evaluated the effectiveness, crop injury, and costs of different herbicide programs for non-flooded rice production.

Hybrid rice was drill planted under center pivots at the University of Missouri- Marsh Farm in Portageville, Missouri. Nitrogen was applied 56 kg urea-N ha^{-1} at first tiller growth stage with 112 kg N ha^{-1} split in five weekly UAN fertigations. Fungicide was applied by chemigation for blast control.

Herbicide treatments were applied to small plots in replicated, randomized complete blocks. Chemicals were applied post-emergence on July 13 with a CO_2 backpack sprayer. Treatments were: 1. Untreated check, 2. propanil, 3. Loyant, 4. Sharpen, and 5. Grandstand™. Each plot was visually rated 6 days and 21 days after treatment.

The primary weed in plots was palmer pigweed. Loyant did an excellent job of killing even large pigweeds with less crop injury than Sharpen (**Figure 4**). Loyant also provides control of

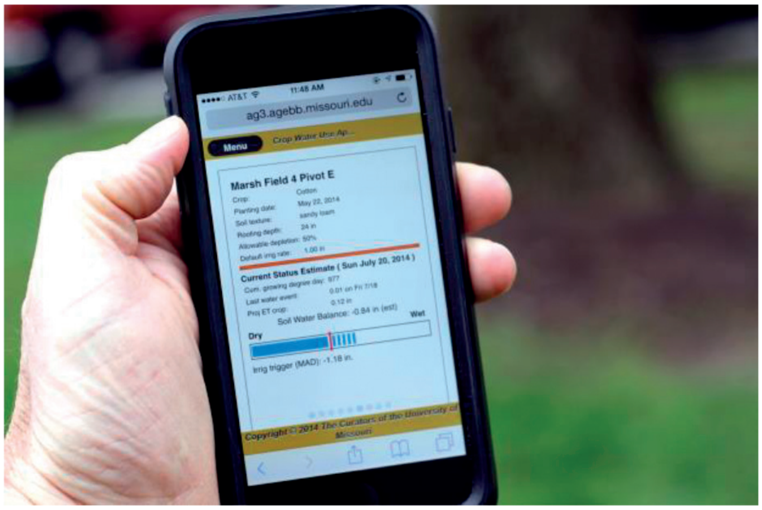

Figure 4. The crop water use app for mobile phones was released by the University of Missouri Extension Service in 2015.

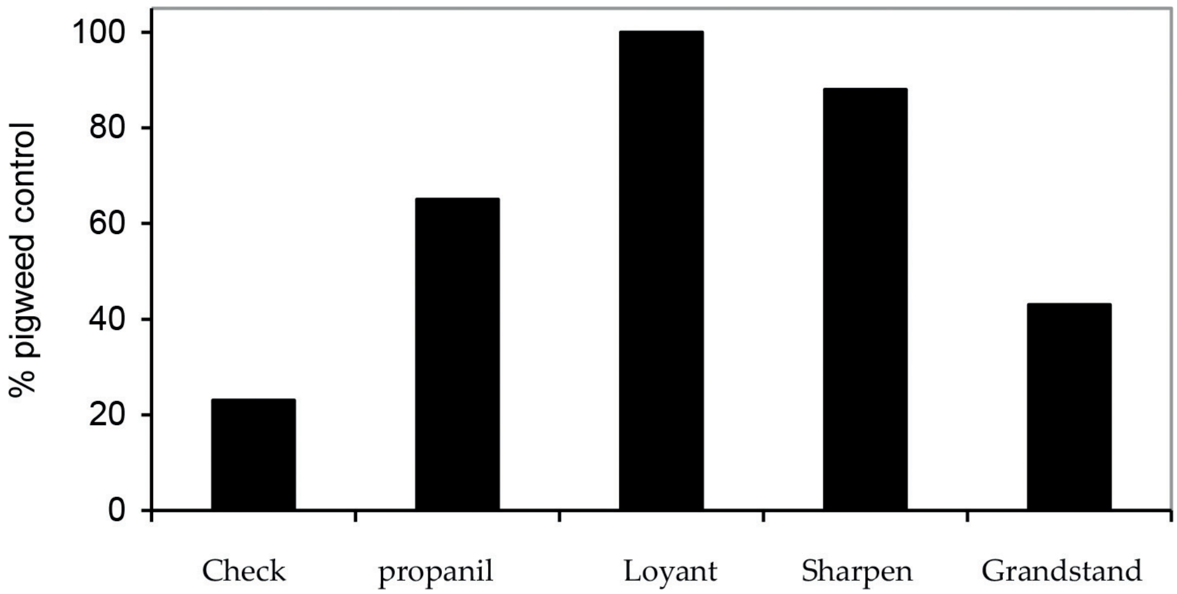

Figure 5. Visual pigweed control on August 3, 2016 (21 days after treatment).

many grass weeds such as barnyardgrass and panicum species in addition to control of rice flatsedge, smallflower umbrella sedge and yellow nutsedge. Of the products evalutated in this study, only propanil offers any grass control. Propanil and Grandstand stunted or burned pigweeds but most recovered and grew back later in the season (**Figures 5** and **6**).

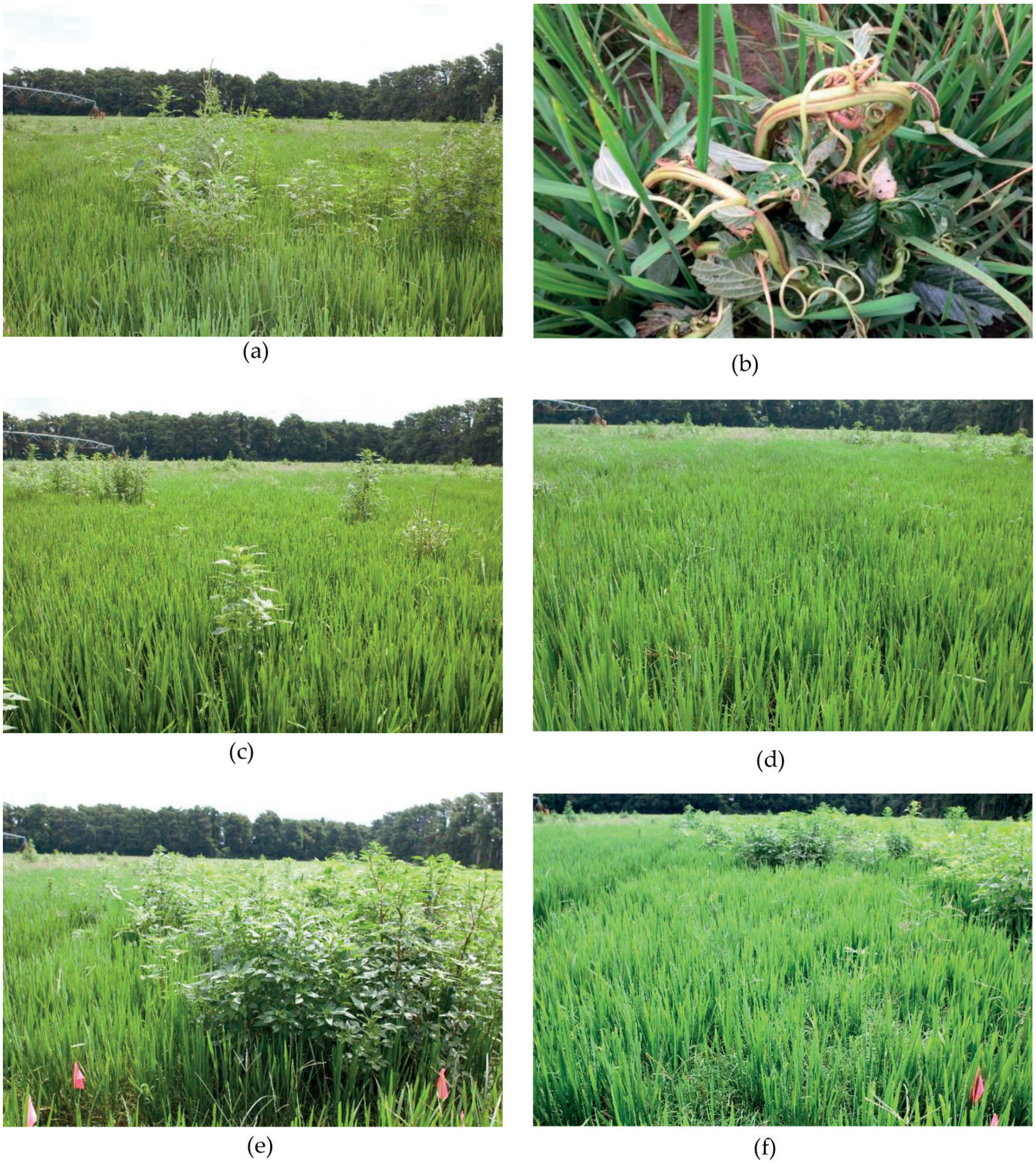

Figure 6. Plot photos from herbicide treatments for center pivot rice in 2016. DAT = Days after treatment. (a) Untreated check, (b) pigweed sprayed with Loyant (6 DAT), (c) propanil (21 DAT), (d) Loyant (21 DAT), (e) grandstand (21 DAT), (f) sharpen (21 DAT).

8. Conclusions

All current cultivars and hybrid grown by farmers were bred for production with flood irrigation. Field trials showed that some lines are more productive with furrow irrigation than others. Scheduling irrigation application using weather based evapotranspiration calculation will take the guess work out of optimizing irrigation timing and rates. Applying nitrogen after internode elongation improved yields. New herbicide chemistry will help control problem weeds such as Palmer amaranth pigweeds.

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