A Model to Predict Safe Stages of Development for Rice Field Draining and Field Tests of the Model Predictions in the Arkansas Grand Prairie

P. A. Counce,* K. B. Watkins, K. R. Brye, and T. J. Siebenmorgen

ABSTRACT

Due to the cost of extracting water, effective and efficient utilization of irrigation water for rice (*Oryza sativa* L.) is critical to rice farm profitability. The objective of this study is to predict safe stages of development for draining rice. This objective has the potential of saving rice farmers water. A computer program has been developed to predict the stage of development for draining water from rice field soils at which the risk of reduced grain yield or milling quality from insufficient water is considered to be near zero. The parameters of the model are predictions of (i) temperature during rice reproductive growth stages (RRGS) starting at R3, (ii) timing of various RRGS, (iii) maximum amount of water used by the rice crop at each growth stage, and (iv) the water held in the soil profile after draining which is available to the rice crop. The central goals of the model are to allow draining at an RRGS in which (a) the danger of reducing yield and quality from water deficits is at a minimum and (b) water is conserved and land conditions for harvest are improved. Experiments to test the predictions were conducted in 2005 and 2006 at two Arkansas locations: Gillett and Stuttgart. An experiment was also conducted at DeWitt, AR, in 2006. Draining at stages of development predicted by the model did not affect yield milling quality relative to the control for any year or location. Predicted water savings from reduced irrigation ranged between \$10.26 to \$55.44 ha^{-1} depending on pump depth. Implementation of the program can save money, reduce tillage costs, and reduce unnecessary depletion of the aquifers.

Several important reasons for conserving water in rice production exist. Subsurface water is expensive to extract, the aquifers are being depleted at an unsustainable rate, water is needed for irrigating other crops such as soybean [*Glycine max* (L.) Merr.] at critical reproductive stages of development, and leaving water on the field too long can result in increased tillage costs, harvesting problems, and crop loss. A typical irrigation of a rice field will be approximately 7.62 cm (or 3 in), which costs from \$10.26 to 55.44 ha^{-1} (Table 1). The cost of extracting water for irrigation is a significant proportion of the costs of producing rice (Watkins et al., 2006). Irrigation from an aquifer is not sustainable when average withdrawal rates from an aquifer exceed average recharge rates (Czarmecki et al., 2003; Custudio, 2002; Sophocleous, 2000). Aquifer depletion is a matter of public record: in eastern Arkansas and withdrawal rates have exceeded recharge over a period of at least 40 yr (Scott et al., 1998). Moreover, at the time of year in which rice irrigation water may be reduced, soybean yields respond most to irrigation and irrigation is often unavailable to soybean (Popp et al., 2005). If rice lodges before draining, seeds will rapidly sprout or deteriorate and yield and quality loss can be extensive. Consequently, growers need to know when rice can be drained without reducing grain yield or milling quality.

Table 1. Variable cost savings associated with a 7.62 ha cm reduction in applied water for varying pump lifts.

Variable cost item	Pump lift, m					
	15	30	45	60	75	90
Diesel consumption, l ha^{-1} cm^{-1}†	1.67	3.34	5.01	6.68	8.35	10.02
Fuel and lubrication, \$ ha^{-1}‡	8.51	17.01	25.52	34.02	42.53	51.04
Repairs and maintenance, \$ ha^{-1}§	0.69	0.69	0.99	0.99	3.34	3.34
Labor cost,\$ ha^{-1}¶	1.06	1.06	1.06	1.06	1.06	1.06
Total cost, \$ ha^{-1}	10.26	18.76	27.57	36.07	46.93	55.44

† Diesel consumption was varied by pump lift based on Bryant et al. (2001).

‡ Fuel consumption for 7.62 ha cm multiplied by \$0.58 per l for on-farm diesel (Watkins et al., 2007) plus \$0.087 per l for engine oil.

§ Derived from 2006 Arkansas rice budgets (Watkins et al., 2006). Values for deeper pump lifts were adjusted upward to reflect greater repair expenditures for larger wells.

¶ Derived from 2006 Arkansas rice budgets (Watkins et al., 2006). These calculations assume a labor wage of \$8.12 h^{-1}.

Earlier research indicated rice fields could be drained 2 wk earlier than usually practiced without reducing rough rice yields or milling quality (Counce et al., 1990, 1993). Counce et al. (1990) drained rice at 0, 2, and 4 wk after 50% heading in fields at three locations in eastern Arkansas. Typically, rice was drained around 25 to 28 d after 50% heading for long-grain cultivars and 35 d for medium grain cultivars. Rough and head rice yields were reduced by draining at 50% heading in some years on both silt loam and clay soils, but draining at 2 wk after 50% heading did not reduce rough or head rice yield in any year or location in these tests. Research by others in Arkansas and Texas has confirmed these results (Grigg et al., 2000; McCauley and Way, 2002). This indicated that rice could be

Abbreviations: RRGS, rice reproductive growth stage; GDD, growing degree days; HRY, head rice yields.

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safely drained considerably earlier than was practiced by most farmers. Earlier draining would directly decrease production costs associated with decreased irrigation. Indirect cost savings from timely draining would result from a decreased need for tillage to repair harvesting ruts that are common with late irrigation. The production of ruts increases tillage and harvest costs and essentially eliminates the possibility of pursuing a no-till system. The cost of repairing ruts in a field is conservatively estimated at \$62 ha^{-1} (T. Gray, personal communication, 2006). When red rice seed remain on the soil surface after harvest they germinate rather quickly (Gealy et al., 2000). When seeds are buried, however, they do not germinate but rather enter into a state of dormancy (Noldin et al., 2006). Consequently, producing ruts in a rice field exacerbates red rice management problems.

Since the draining research described by Counce et al. (1990, 1993) was completed, a rice growth staging system has been developed to allow clear communication among farmers, researchers, extension personnel, and others working with rice (Counce et al., 2000). Research on the growth-staging project has allowed time intervals to be established between the different RRGS after heading (Watson et al., 2005; Clements et al., 2003). This is partially because of the objective features of the staging system, which allows clear determination of each growth stage by comparing plants with criteria which are either present or absent (Counce et al., 2000). Tests indicated rice yield was sensitive to water stress through grain maturity (Yoshida, 1981; P.A. Counce, personal communication, 2008). This is true for a large number of grain and seed crops. For instance, corn (*Zea mays* L.), soybean, and grain sorghum (*Sorghum bicolor* L.) crop yield can be reduced due to water deficits until physiological maturity of grain or seeds (Klocke et al., 1991).

Rice can in some cases be drained at 2 wk after 50% heading without reducing yield or quality but the plant is sensitive to drought stress until the kernels have filled. The soil profile holds water available for plant uptake after draining which can prevent drought stress. Furthermore, as the crop approaches maturity the amount of water used by the crop progressively declines.

To aid rice producers in end-of-season draining decisions, a computer program was developed to predict the safe growth stage for draining rice fields–the growth stage at which rice can be safely drained. Input data needed are soil series, rooting depth, and projected (or actual) date of 50% heading. Outputs from the program are a predicted growth stage and date of that stage for safely draining the rice field without reducing grain yield or milling quality.

Table 2. Projections of growing degree days (GDD) per rice reproductive growth stage (RRGS), typical minimum and maximum days per RRGS in "typical" rice growing seasons on the Arkansas Grand Prairie and maximum water use projections per day for rice at various RRGS.

RRGS	GDD	Typical minimum days in RRGS	Typical maximum days in RRGS	Maximum rice crop water use
	°C d^{-1}	d		mm d^{-1}
R3	51	3.7	4.6	6.5
R4	64	4.6	5.8	6.0
R5	47	3.4	4.2	5.3
R6	84	6.0	7.6	4.8
R7	84	6.0	7.6	3.0
R8	197	14.2	17.7	2.0

Acceptance of early draining concepts by farmers has been hindered by the lack of a definitive framework for making the decision. One objective of this research was to first develop a predictive model for safe draining based on soil characteristics, crop developmental rate, and crop water use. The second objective was to evaluate differences in grain yield and milling quality when soil was drained at developmental stages predicted by our model compared to conventional later dates.

MATERIALS AND METHODS

The Model

The model consists of four information components: (i) a historical temperature database for Stuttgart, AR, (ii) a database for growing degree days (GDD) per RRGS, (iii) maximum water use projections per RRGS, and (iv) soil water availability to the rice crop determined from soil type and published water availability values for various soils.

Historical Temperature Database

The weather station at the University of Arkansas Rice Research and Extension Center has been in service for more than 56 yr. The temperatures from the mean of these years were used to project GDD for the crop in 2006. In 2005, the assumed daily GDD projection was 25 (see below Eq. [1]). The projected temperature maximum and minimum values were taken from the historical database based on the 50% heading date (date when 50% of the expected panicles have emerged from a given plot or field). The historical weather database was used in 2006 but in 2005, an assumption was made based on a slightly different database (see next section Growing Degree Days Projections of Reproductive Stages of Development).

Growing Degree Days Projections of Reproductive Stages of Development

The GDD projections for various rice developmental milestones were developed several years ago (Keisling et al., 1984). These projections have been used extensively in the southeastern U.S. rice producing areas. The rice growth staging system was developed to provide an objective, adaptive, and uniform method for describing rice development (Counce et al., 2000). There are 10 RRGS for the rice growth staging system. Reproductive development consists of 10 growth stages based on discrete morphological criteria for the main stem panicle: panicle initiation (R0), differentiation of panicle branches (R1), flag leaf collar formation (R2), panicle exertion (R3), anthesis (R4), grain length expansion to the end of the hull has begun for at least one main stem caryopsis (R5), at least one main stem caryopsis has completely elongated to the end of the hull (R6), at least one main stem grain has turned yellow (R7), at least one main stem grain has turned brown (R8) and complete panicle maturity (R9). By observing daily growth stages, GDD projections between successive RRGS were determined (Table 2). From these determinations, the periods of time between successive stages of development can also be calculated:

$$\mathrm{GDD} = \sum_{i=m}^{n}(\mathrm{T_A} - \mathrm{T_B}) / \Delta t \quad [1]$$

where T_A is the average of daily maximum (T_{max}) and daily minimum (T_{min}) air temperatures. T_B is the base temperature below which development is presumed to cease (Dwyer et al., 1999). The term Δt refers to the time step for the calculation, in this case, 1 d. In rice, the base temperature is set at 10°C (Keisling et al., 1984). Furthermore, development above 34.4°C for T_A and above 21.1°C for T_B were expected to result in no increase in development. If GDD is computed as less than zero then it is set to zero.

Beginning with the date of R3, days in each successive RRGS were predicted by calculations of GDD for each RRGS in Table 2 from Watson et al. (2005). Thus days in each RRGS are calculated by the following equation:

$$d_{rrgs} = GDD_{rrgs}/GDD_d \quad [2]$$

where d_{rrgs} = days per rice reproductive growth stage and GDD_d = days per growing degree days in a selected time period beginning at the R3 stage. Temperature projections were used to generate dates at which each successive growth stage would be reached. These dates were determined from the historical weather database in 2006. In 2005, 25 GDD d^{-1} were predicted to be accumulated.

Maximum Water Use by the Rice Crop per Rice Reproductive Growth Stage

Published water use amounts from field experiments form the basis for this part of the model (Lage et al., 2003; Renaud et al., 2000). Lage et al. (2003) presented maximum water use at the R3 growth stage. Maximum water use at other growth stages was estimated from season-long measurements (Lage et al., 2003; Renaud et al., 2000). We multiplied maximum water use per day for each RRGS (Table 3) by the projected number of days for the RRGS. The product was the maximum water use per RRGS.

$$MCWU_{rrgs} = MCWU_d \times d_{rrgs} \quad [3]$$

Where $MCWU_{rrgs}$ = maximum crop water use per rice reproductive growth stage and $MCWU_d$ = maximum crop water use per day at each respective RRGS (Table 3) and d_{rrgs} from Eq. [2].

Soil Water Available to the Rice Crop

Davis (2002) measured soil physical and hydraulic properties for several soils including the two soils in this study: (i) DeWitt silt loam (fine, smectitic, thermic Typic Albaqualfs) and (ii) Stuttgart silt loam (fine, smectitic, thermic Albaquultic Hapludalfs). The measured bulk density and gravimetric water retention at 1500 kPa of applied pressure, which approximates the permanent-wilting-point water content, from the 5 and 15 cm depth were averaged to obtain values to represent the top 10 cm of soil. Total porosity was calculated from the mean bulk density and assuming a particle density of 2.65 g cm^{-3}. The saturated soil water content (θ_{sat}) was assumed equal to the calculated total porosity. The mean gravimetric water retention at 1500 kPa was multiplied by the mean bulk density to express water retention on a volumetric basis (WR_{1500}). The mean volumetric WR_{1500} used for both the DeWitt and Stuttgart soils was 0.11 mm^3 mm^{-3}. The total amount of water stored in the root zone and potentially available for uptake by rice was determined by the following equation:

$$ASW = (\theta_{sat} - WR_{1500}) \times Dz \quad [4]$$

where ASW is the potentially available soil water (in mm) for uptake by the rice crop, θ_{sat} and WR_{1500} are as defined above, and Dz is the thickness of the rooting zone (in millimeters). The amount of water available to the rice crop at draining (i.e., ASW) for the DeWitt and Stuttgart soils were 0.429 and 0.384 mm mm^{-1}, respectively.

Table 3. Projected water use from various stages of development to the R9 stage of development, water use projected in the root zone and predicted safe stage of development for draining for three Arkansas locations over 2 yr.

	Projected water use				
	2005		2006		
RRGS interval	Gillett	Stuttgart	DeWitt	Gillett	Stuttgart
	mm				
R3–R9	142.4	145.1	118.2	137.5	137.5
R4–R9	118.5	121.1	98.7	113.6	113.6
R5–R9	91.0	93.5	76.2	86.0	86.0
R6–R9	73.0	75.5	61.5	68.0	68.0
R7–R9	44.0	46.5	37.9	39.0	39.0
R8–R9	28.4	28.4	23.1	20.9	20.9
Water in root zone	76.8	45.7	38.4	45.7	45.7
Safe RRGS	R6	R8	R7	R7	R7

Depth of the Root Zone

Since >95% of the rice roots have been shown to be concentrated in the top 200 mm of soil (Sharma et al., 1994; Beyrouty et al., 1996), it was assumed that no water is extracted below the 200-mm soil depth even in the absence of a tillage pan. Penetrometer readings were made, when the soil was at or near saturation, to a depth of 400 mm for each site. The rooting depth was assumed to be reached with the penetrometer when the soil resistance reached 2.0 MPa (Gajri et al., 2002). The plow layer in these Prairie soils is so pronounced, however, that it can be clearly determined with a shovel, soil probe, or steel bar. With the exception of the Gillett location in 2005, the depth of the root zone was 100 mm. At Gillett in 2005, the rooting depth was 200 mm due to the 2.0-MPa impedance reading being reached at that depth. The amount of water available to the crop was determined by Eq. [4] using the appropriate rooting depth for each location.

Synthesis

The model that was developed is a specialized, yet conservative and practical, water budget for a rice crop. Beginning with the R9 stage of development and working backward, water use is summed with the amount of water extracted at the R8 stage. The amount of water extracted between the R8 to R9 stage was compared to the amount of water remaining in the soil. If there is more available water in the soil than the crop extracts from the R8 to R9 stage, the amount of water extracted from the R7 to R9 stage is compared to the available soil water. If there is more water in the soil than the crop extracts from the R7 to R9 stage, the amount of water extracted from the R6 to R9 stage is compared to the available soil water. The soil contains a reservoir of available water when draining is complete. Beginning at maturity and working in a stepwise manner backward from maturity, the water extracted is summed. As long as the water extracted from an RRGS to maturity is less than or equal to the amount of water in the soil reservoir, it is assumed safe to drain at that stage. The program allows for the determination of the earliest RRGS at which plant extraction is less than or equal to the amount of water available in the soil.

Experiments

Five field experiments were conducted over 2 yr. Each experiment was arranged as a randomized complete block with four replications. Data were submitted to analysis of variance. There were two treatments in all experiments: (i) drain at the safe growth stage as determined by the growth stage model computer program and (ii) a control treatment which was a conventional, later drained treatment. At the Gillett site there was a third treatment described below. The control treatment time of draining varied according to the farm practices (DeWitt and Gillett sites) or extension service recommendations (Stuttgart site). To accomplish the draining treatments on farm fields, steel frames were constructed and driven into the soil to accomplish a later draining than the field around a plot. These were driven into the soil to (or past) the plow layer. These frames had two 50-mm holes cut at ground level to allow access to water into the plots. At the time of draining, these holes were plugged with No. 11 rubber stoppers and the standing water removed from the area within the frames by either allowing the flood to dry up in 2005 (which occurred in that case within 1 d) or by pumping the surface water out of the frames (2006). To determine the depth of the root zone as part of Eq. [5] for predicting water available from the soil, penetrometer measurements were made over the experimental areas. Model calculations for water use [Eq. [1]–[3]), predicted soil water availability (Eq. [4]] and predicted safe RRGS for draining [*Synthesis*] were done for each location in each year (Table 3). All experiments were located on either a Stuttgart silt loam or a DeWitt silt loam. With one exception, the cultivar planted in the experiments was Wells (Moldenhauer et al., 2007b). The exception was the 2005 experiment at Gillett, in which the cultivar planted was Francis (Moldenhauer et al., 2007a).

An experiment was conducted in a production rice field near DeWitt, AR(34°18′ N, 91°18′ W) in 2006. The soil was a Stuttgart silt loam. There were two treatments in the experiment: (i) drain at the safe growth stage as determined by the growth stage model computer program and (ii) drain as the farmer drained the field—this was a control treatment without a frame with the same plot dimensions as plots of Treatment 1. The plots were 1.22 by 2.45 m. Treatment 1 plots were bordered by 14 gauge sheet metal 200 mm above the soil surface and driven into the soil 100 mm below the soil surface (the depth of the plow layer).

Two experiments were conducted in production rice fields near Gillett, AR (34°11′ N, 91°41′ W). The soil was a Stuttgart silt loam. The plots were 1.22 by 2.45 m bordered by 14 gauge sheet metal 200 mm above the soil surface and driven into the soil 200 mm below the soil surface (the depth of the plow layer). The sheet metal borders were installed within 2 wk of crop emergence at which the growth stage was approximately V1 to V3 (Counce et al., 2000). There were three treatments: (i) drain at the safe growth stage as determined by the growth stage model computer program with a frame, (ii) drain as the farmer drained the field with the frame around the rice, and (iii) drain as the farmer drained the field without a frame.

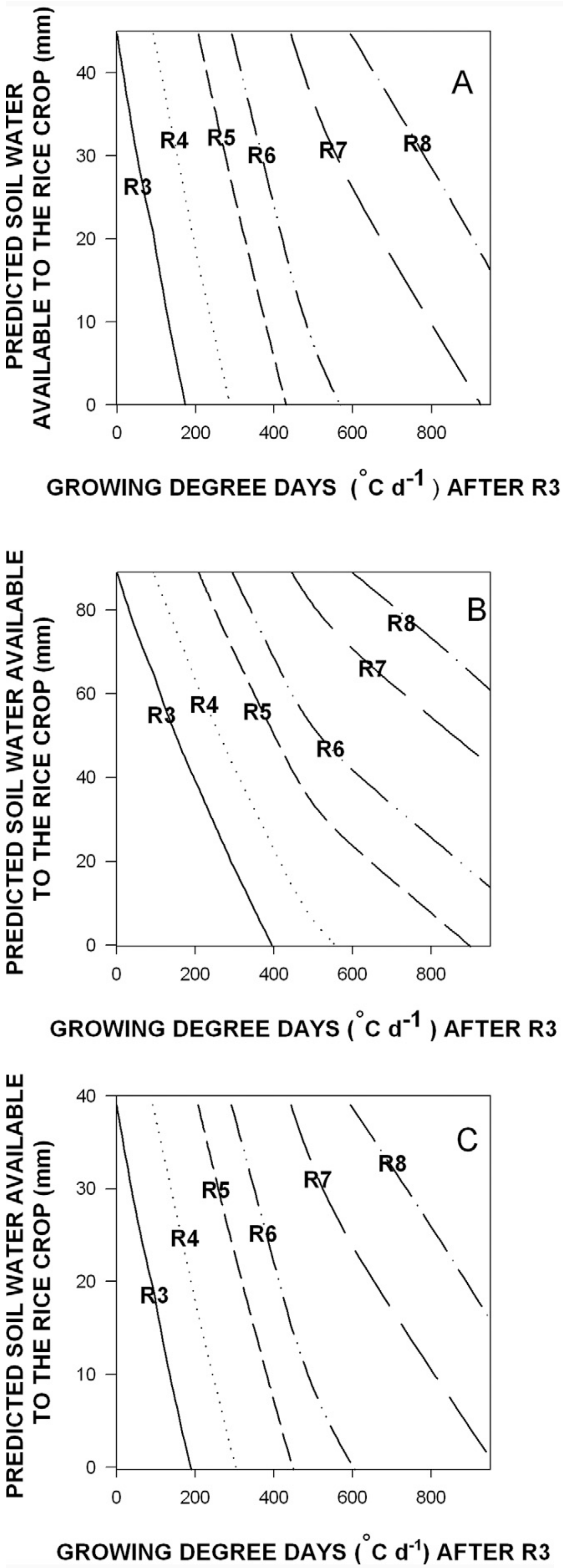
The experiments at Stuttgart (34°28′ N, 91°25′ W) had two treatments: (i) drain at the safe stage of development predicted by the growth stage model computer program and (ii) drain at 28 d after 50% heading. Harvested areas at Stuttgart were 2.5 by 9.2 m. The soil was a DeWitt silt loam. In 2006, an additional harvested area was 6 by 46 m. Each plot was bounded by its own normal earth levees. A bar ("borrow") ditch was adjacent to and between the levee and flat area planted to rice.

Plots were harvested by hand with a sickle and threshed with a stationary thresher. Rough rice harvest moisture content, yield, and milling quality were determined shortly after harvest for each plot. In 2005, grain was dried in shallow metal pans at 22°C and 50% relative humidity until equilibration moisture content (~11.9–12.3%) was reached. Grain from each plot was subsequently stored in two plastic bags within each other at ~7°C until it was analyzed for brown, milled, and head rice yield. In 2006, grain was dried in shallow metal pans in the lab for a few hours and then placed in two plastic bags within each other at approximately ~7°C until it dried with precision drying environmental conditions. Thereafter brown, milled, and head rice yield determinations were made.

RESULTS AND DISCUSSION

Predicted water availability with draining at RRGS from R3 through R8 are presented in Fig. 1. The x axes are GDD after R3. The y axes are available soil water. The x axes are projected dates for projected plant water availability from each RRGS to R9 (grain maturity). Beginning at the projected dates for each successive RRGS after R3, available water after draining was predicted. When the amount of available water reached zero before projected R9, it was too early to drain. At Stuttgart in 2005, the projected safe drain RRGS was R8 (Fig. 1a). At Gillett in 2005, the projected safe drain RRGS was R6 (Fig. 1b). At all three locations in 2006, the projected safe drain RRGS was R7 (Fig. 1c,d,e). The differences in projected safe draining RRGS for 2006 (being earlier than those of 2005) are the result of projected temperatures. The temperatures in 2005 were projected to be cooler than those in 2006, this lead to longer periods between each RRGS. Since maximum water use was projected per day, this increased the projected water use per RRGS in 2005 relative to 2006.

Rough rice yields did not differ based on draining treatments in any of the five experiments in this study (Table 4). In Gillett in 2006, the treatments with plots bounded by metal frames did not differ in rough rice yield. Part of the experiment was to establish whether the control plots needed to be bounded by the metal frames. In other words, the two control treatments at Gillett were done to experimentally separate the effect of the metal borders and that of draining without metal borders. There were no differences in the draining treatments in 2005 or 2006. In 2006, there was a statistically significant yield difference between the areas bounded by metal frames and those without. The numbers of culms per plot were counted for each plot. Plots without metal frames in 2006 had more culms m^{-2} than the bounded areas. Culms m^{-2} were 384 for the draining



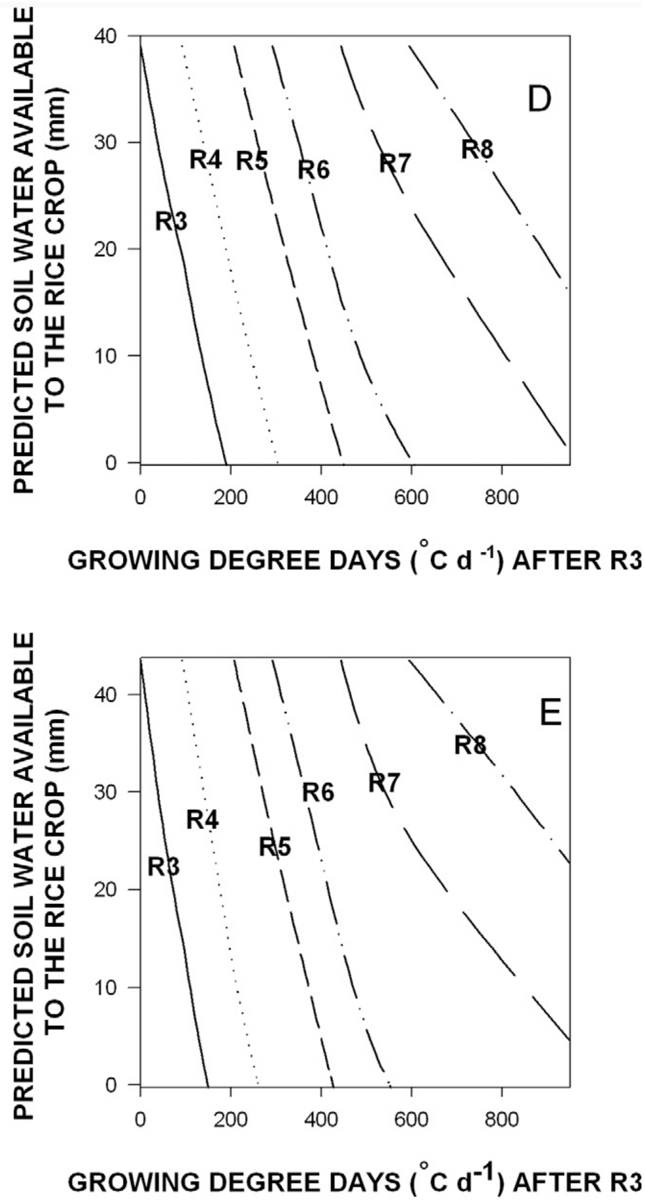


Fig. 1. Predicted water available to the rice crop after draining for five location/year combinations of draining experiments: (a) Stuttgart in 2005, (b) Gillett in 2005, (c) DeWitt in 2006, (d) Gillett in 2006, and (e) Stuttgart in 2006. The *x* axis is the predicted growing degree days (GDD) accumulation for maturity or R9. For each of six stages of development, the predicted available water is from a designated stage of maturity to R9.

Table 4. Rough rice grain yields from experiments on the Arkansas Grand Prairie in 2005 and 2006.

Treatment	Rice grain yield				
	2005		2006		
	Gillett	Stuttgart	DeWitt	Gillett	Stuttgart
	Mg ha^{-1}				
Drain by program based on computer program prediction	11.52	9.64	8.13	8.43	9.44
Control 1	10.74	9.68	8.54	8.82	9.35
Control with steel frame borders	10.92	na†	na	10.68	na
Draining effect	ns	ns	ns	ns	ns
CV, %	6.00	6.32	7.68	9.95	6.56
LSD(0.05)	1.29	1.20	1.26	2.09	1.21

† na, not applicable; ns, not significant.

Table 5. Head rice yields from experiments in the Arkansas Grand Prairie in 2005 and 2006.

Treatment	Head rice yield				
	2005		2006		
	Gillett	Stuttgart	DeWitt	Gillett	Stuttgart
	g kg^{-1}				
Drain by program based on computer program prediction	654	620	534	559	619
Control	655	630	513	574	620
Control with steel frame borders	661	na†	na	592	na
Draining effect	ns	ns	ns	ns	ns
CV, %	0.90	1.14	2.83	5.42	1.03
LSD(0.05)	12	14	29	61	13

† na, not applicable; ns, not significant.

by program plots, 361 for the Control plots with borders and 446 for the control plots without metal frames. Consequently, when we submitted these plots to analysis of covariance (for culm number which was established before draining), we found that treatments did not differ ($P > 0.05$). Further, we believe the lower populations in some plots were not the result of frames but were the result of soil and other factors already effective at the time of the frame installation. Several factors lead to reduced plant population densities after emergence. These include combinations of insects (especially the grape colaspis [*Colaspis brunnea* F.]), cold weather, and disease (*Pythium* spp., *Rhizoctonia* spp.) (Counce, 2006). Although the effect of the frames cannot be absolutely eliminated, the exclusion of bordering plants within the frames from harvest reduces the likelihood that the frames were a significant yield factor or the cause of the population difference. At any rate, the effect of draining was not significant in the 2006 Gillett experiment and the effect of the metal frames is, at least, subject to question.

Head rice yields (HRY) did not differ for the rice drained based on the model compared to the control plots in any location in any year (Table 5). The HRY is a primary measure of milling quality. Head rice yields is defined as the mass percentage of rough rice grains that remain after milling that are at least three-fourths of the original kernel length after milling. Currently, brokens are sold at <60% of the price of head rice (Siebenmorgen et al., 2007). Because of this premium for head rice relative to brokens, HRY is a direct determinant of economic return. A number of interrelated factors during growing and processing determine rice milling quality.

Table 6. Dates for critical treatment impositions for treatments for experiments to test the draining model conducted at three locations in the Arkansas Grand Prairie.

Experiment	50% Heading date	Date for draining based on program treatment	Date for control treatment
Gillett 2005	23 July	2 August	15 August
Stuttgart 2005	4 August	18 August	1 September
DeWitt 2006	5 July	19 July	24 July†
Gillett 2006	24 July	7 August	15 August
Stuttgart 2006	25 July	7 August	22 August

† Control plots were at saturation on this date although the field was not drained and was allowed to dry up without draining.

Table 7. Precipitation between imposition of draining treatments and harvest for locations in the Arkansas Grand Prairie in 2005 and 2006.

Interval	2005		2006		
	Gillett	Stuttgart	DeWitt	Gillett	Stuttgart
Draining by program to control	0	135	0	8	12
Control to harvest†	51‡	0	0	43	0

† The rainfall from the imposition of control draining until harvest occurred, at all locations and years, during the period in which the crop was at the R8 rice reproductive growth stage (RRGS).

‡ Forty-six of the 51 mm were within 5 d of harvest.

The plots drained by the program projections at Gillett in 2006 had 10 d between 50% heading and draining by program treatment and 13 d between the draining by the program plots and control (Table 6). In the period between imposition of the program draining treatments and control draining, there was no rainfall at the Gillett site in 2005 (Table 7). While there was 51mm of rainfall at the Gillett experiment in 2006, 46 mm of that rainfall fell within 5 d of harvest when the rice crop was at the late R8 RRGS. Consequently, the Gillett test in 2005 was an extremely tough test of the model predictions. For the Stuttgart test in 2005, due to heavy rainfall between imposition of the draining treatments from the program and the control draining dates, soil water content was likely adequate due to rainfall alone. In 2006 at DeWitt, however, even though the draining by program plots were drained only 1 d before ceasing pumping on the control plots, the extremely dry conditions during that period made that treatment a good test of the model's predictions. Further, the Gillett and Stuttgart tests experienced small amounts of rainfall between imposition of draining of the program plots and of the control plots. Consequently, four of the five experiments were likely good tests of the model's predictions.

The water requirements for growing rice are great (Renaud et al., 2000; Lage et al., 2003). The Grand Prairie soils are extremely well suited for growing rice and soybean and less well suited for other crops. A common expression among rice farmers, researchers, and extension personnel is that draining rice is more "art than science". When the cost of extracting water was low, using additional water at the end of the growing season, even without benefit, was seen as "insurance" by farmers and extension workers. The situation with the alluvial aquifer in the Grand Prairie zones of depression is now critical (Scott et al., 1998). A small amount of water extracted from an already depleted resource annually exacerbates a large problem. A fairly large body of research exists to support the proposition that rice can safely be drained earlier than is practiced or recommended

(Counce et al., 1990, 1993; Grigg et al., 2000; McCauley and Way, 2002), the extension service continues to recommend, and many farmers (by no means all) practice, irrigation after the need for that irrigation is past. This simple program for RRGS safe drain date prediction combines soil, crop, and water use data to bring science into the practice of draining rice. Combined with other water conservation practices and development of sources of aboveground water for irrigation, this program can improve the well-being of Arkansas rice producers. One nontechnical definition of sustainability is the ability to continue a practice over a sufficiently long period of time to establish confidence in it continuance. In China, rice production has been carried on for 3 to 5 millennia in its continuance. Chinese yields approach high-input U.S. crop despite the land being cropped to rice 3 to 5 millennia longer than in the U.S. rice producing areas.

CONCLUSION

The model predictions could lead to reduced water costs for rice production, increased water availability for soybean production, decreased tillage costs, and a reduction in the drawdown from the depleted aquifers. These considerations are critical to both the sustainability of the farm economy in the Arkansas Grand Prairie and to the future availability of economical sources of water. Further research needs to be done including testing of the model in other soils in other rice producing areas. Also, the RRGS intervals likely differ between cultivars (Watson et al., 2005). The RRGS timing datasets are needed for all widely used rice cultivars so the model can be used with a broad range of cultivars.

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