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Investigating irrigation scheduling for rice using variable rate irrigation

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ABSTRACT

Because almost all US rice is produced with continuous flood irrigation, little information addresses irrigation scheduling for rice; however, successful production without a continuous flood will require timely irrigation. A field study conducted at the University of Missouri Fisher Delta Research Center Marsh Farm during the 2013 and 2014 growing seasons investigated irrigation scheduling for sprinkler irrigated rice. Two irrigation timings were based on management allowed depletion (MAD) (MAD1: 10 mm application at a 12 mm estimated soil water deficit (SWD); MAD2: 15 mm application at a 19 mm estimated SWD). For each MAD treatment, three VRI settings represented 75, 100, and 125% of the target applications. Seven fewer irrigations were applied to MAD2 plots in 2013 and eleven fewer in 2014 but larger applications resulted in similar total application amounts. Neither treatment main effect was significant for yield in 2013, but there was a significant interaction, with differences among the % application treatments for MAD2. The % application main effect was significant for irrigation water use efficiency and there was a significant interaction. Yields were lower in 2014 than in 2013, which was expected given the late planting and soil compaction that resulted from land grading. Soil moisture data were inconsistent, and variability among the sensors led to few significant differences. Yield was significantly greater than the field average for only one treatment combination (MAD1 – 100%) and significantly lower for two (MAD2 – 75, 100%). Irrigation water use efficiency of two of the treatment combinations was significantly greater than the field average (MAD1 – 75%, MAD2 – 75%) while two were significantly lower (MAD1 – 125%, MAD2 – 125%). While the findings suggest that sprinkler irrigated rice performed equally well under a range of irrigation management, additional research is needed to validate these trends and develop improved guidelines for producers.

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1. Introduction

The Lower Mississippi Water Resource Area (WRA 08, also called the Mid-South) contains more than 4.6 million ha of farmland in portions of the US states of Missouri, Kentucky, Arkansas, Tennessee, Mississippi, and Louisiana (USDA-NASS, 2014). Mid-South farmers grew almost 0.7 million ha of rice in 2013, 53% of the total US rice crop (USDA-NASS, 2014). In parts of the world, a portion of the rice crop is produced in an upland, rainfed culture; however, US-produced rice is grown almost exclusively in a flooded culture. In the dry-seeding system commonly used in the Mid-South, the crop is flooded at approximately the V-4 growth stage (Counce et al., 2000) and a continuous flood is maintained until after heading. Failure to maintain sufficient flood depth results in dry portions of the field, increased weed and fertilizer problems, and low yields. Excessive irrigation wastes water and energy and increases pressure on levees. In addition, soil, fertilizers, and pesticides may be carried in runoff from over-watered agricultural fields.

Hogan et al. (2007) estimated that flood irrigation for a rice crop required more than twice as much irrigation water as the methods used with other crops grown in the Mid-South, but field observations vary greatly. Vories et al. (2006) reported a range of 460–1435 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. The Yazoo Mississippi Delta Joint Water Management District reported an 8-year (2002–2009) average irrigation water use of 914 mm in Mississippi, with a range of 579–1158 mm for 24 rice fields in 2009 (YMD, undated).

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Irrigation efficiency is a term that is often used but not well understood. Application efficiency is generally defined as the ratio of the volume of irrigation water stored in the root zone and available for evapotranspiration (ET) to the volume delivered from the irrigation system (Smajstrla et al., 2002). For continuous flood irrigation, the volume delivered must not only be adequate to provide for ET, but also to maintain the desired flood depth. Burt et al. (2000) reported the potential application efficiency for continuous flood irrigation, the method used for most Mid-South rice, is 80% under practical conditions, which is within the range they reported for center pivot systems (75%–90%). In practice, however, water is lost from rice fields through runoff from the field, seepage through outside levees, and deep percolation below the root zone.

Another useful value for evaluating irrigated crop production is irrigation water use efficiency (IWUE). Although not all authors use the same definition, in this report IWUE was defined as the ratio of the increase in grain yield above rainfed production to the volume of water applied by irrigation, or the additional yield produced per unit of irrigation water applied. For the rice varieties produced in the US and the Mid-South climate, rainfed yield can be assumed 0. Vories et al. (2005) reported average IWUE values of 0.9 and 1.2 kg m^{-3} for producer rice fields using conventional flooding and multiple inlet irrigation, respectively.

Producers and researchers have looked for ways to use less water for rice production and center pivot systems typically have high application efficiencies, with published values as high as 90% (Burt et al., 2000). Rice studies with center pivot irrigation during the 1980s in Louisiana (Westcott and Vines, 1986) and Texas (McCauley, 1990) reported large yield reductions compared with flooded production. Naturally, producers will not readily abandon flooded production for an alternative system that produces lower yields and the practice was not widely adopted. However, interest in the center pivot method has increased since the earlier studies were conducted and Stevens et al. (2012) provided an overview of recent research on center pivot irrigation of rice. In addition, recent studies reported comparable yields between center-pivot irrigated and flooded rice on a producer's field (Vories et al., 2010) and in a controlled study (Vories et al., 2013). Furthermore, producers are constantly looking for additional options in crop choice on fields not well suited to flooded production and Vories et al. (2013) demonstrated the feasibility of center pivot irrigated rice production on coarse-textured soils.

Knowledge of soil properties is essential for efficient irrigation and apparent electrical conductivity (EC_a) of the soil profile is a sensor-based measurement that can provide an indirect indicator of important physical and chemical properties. Since most Mid-South soils are low in salinity, conductivity variations are primarily a function of soil texture, moisture content, and CEC (Rhoades et al., 1976). Sand blows and fissures, which are similar to sand blows but linear in nature (Freeland et al., 2008), can be quite important to irrigation management due to the low plant-available water associated with sand. While the sand blow areas should appear as relatively low EC_a, they are often small in area and may be missed in the survey procedure or difficult to differentiate from the surrounding soil. By supplementing currently available information with sensor data, it should be possible to better understand soil variability and its impact on irrigated crop production, which will be beneficial in the selection of management zones for site-specific application of water and nutrients with variable rate irrigation (VRI) systems.

Yield monitors and other sensors create extensive datasets and Geographic Information Systems (GIS; e.g., ArcMap, ESRI, Redlands, Calif.) have been developed for managing and manipulating them. Furthermore, because the high-density datasets tend to violate some of the assumptions inherent in traditional statistical methods such as analysis of variance (ANOVA), different types of analyses are required. As the theories behind spatial statistics have become better understood, software packages have been developed for analyzing the large, spatially referenced datasets (e.g., GeoDa, GeoDa Center for Geospatial Analysis and Computation, Arizona St. Univ., Tempe AZ).

These changes have impacted agricultural research methods. The problem of soil variability has traditionally been addressed by reducing plot size and assuming that the resulting experimental units were homogeneous with no spatial autocorrelation, at least within replicates. Large-plot data are often analyzed with the same assumptions; however, inferences developed from ANOVA results are compromised when spatial autocorrelation is present in the data (Griffin et al., 2004). The Moran's I test statistic of the aspatial (i.e., not spatially referenced) ordinary least squares (OLS) regression residuals is a measure of spatial autocorrelation and can be interpreted as a spatial correlation coefficient (Anselin, 1988). Values range from −1 to 1, with high positive values of Moran's I interpreted as high (low) values having neighbors of high (low) values. A negative Moran's I signifies high and low value observations occur as neighbors. Site-specific yield data tends to be strongly positively spatially autocorrelated at the density at which yield monitor data are collected (Griffin et al., 2007). In addition, raw yield monitor data contain a variety of inherent errors and researchers have reported that 10–50% of the observations in a given field should be removed (Sudduth and Drummond, 2007).

Finally, because almost all US rice is produced with continuous flood irrigation, there is little information addressing irrigation scheduling for rice. Successful production of rice without a continuous flood will require timely irrigation and thus accurate measurements or estimates of soil water deficit (SWD) for irrigation scheduling. Vories et al. (2013) proposed a basal crop coefficient (K_{cb}) for non-flooded rice that was added to a beta version of the Arkansas Irrigation Scheduler (AIS; Cahoon et al., 1990). The AIS uses a dual crop coefficient approach to calculate a water balance to use in scheduling irrigation, similar to managing a checkbook. The system balance represents the SWD, the difference between the soil's existing moisture content, summed over the rooting depth, and the moisture content of the soil at its well-drained upper limit (~24 hours after surface water was removed). 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 after the earlier publication. The objective of this research was to produce rice on center pivot irrigated, coarse-textured soil using the beta version of the AIS to schedule irrigation to develop guidelines for producing sprinkler irrigated rice.

2. Materials and methods

2.1. Experimental site

A field study was conducted at the University of Missouri Fisher Delta Research Center Marsh Farm at Portageville (36.41° N, 89.70° W) during the 2013 and 2014 growing seasons to investigate sprinkler irrigated rice production. The square field is approximately 10 ha, 320 m along either side, with the primary slopes in the south to north direction (Fig. 1). It is located roughly 14 km west of the Mississippi River and lies within the New Madrid Seismic Zone. The combination of alluvial, eolian, and seismic activity over the years has resulted in highly variable soils in the region. While activities such as precision land grading have made the variability less obvious in many areas, it still exists.

Soil mapping units within the study field included Tiptonville silt loam (fine-silty, mixed, superactive, thermic Oxyaquic Argiu-