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Impact of Planting Arrangement and Drill Row Spacing for Direct-Seeded, Delayed Flood Rice

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Impact of Planting Arrangement and Drill Row Spacing for Direct-Seeded, Delayed Flood Rice

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ABSTRACT

Direct-seeding is the most frequently utilized planting practice in Arkansas and Mid-South rice (*Oryza sativa* L.) production. Enhanced plant density and more rapid rice canopy formation may result from the implementation of innovative plant arrangements and spacings. Studies were initiated in 2019 and continued into 2020 to examine different cultural management practice experiments, including evaluating the impacts of planting arrangement, row spacing, and seeding rates on rice stand density, canopy coverage, grain yield, and milling yield. These small-plot trials were conducted at two locations, a silt loam site and a clay site, representative of soils produced to rice in eastern Arkansas. Stand counts were taken on rice plants in each study at the V2-V3 leaf growth stage. Canopy coverage formation was evaluated in the planting arrangement study by photographing each plot at both locations. Beginning at the V5 growth stage, three sets of canopy coverage images were captured approximately seven days apart. In the pureline variety Diamond, the highest percent canopy coverage was with the highest seeding rate. For each lower seeding rate, the percent canopy coverage was lower. In hybrid cultivar RT XP753, the highest seeding rate resulted in at least 4.48 percentage points greater canopy coverage than the 108, 75, and 43 seeds m^{-2} seeding rates. The results of this study suggest that there is potential for rice grain yield increase with a crossed planting arrangement, but it is not yet known if that is an economically sound decision. Results from the row spacing study indicate that a narrower rice row spacing higher grain yield is obtained. Further evaluations, including additional row spacings, are necessary to determine the ideal row spacing for maximum yield potential of common cultivars planted today.

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CHAPTER ONE: Literature Review

Rice Overview

Acreage and Production

In 1902, the first rice (*Oryza sativa* L.) crop was grown in Arkansas on under half a hectare. The state of Arkansas continued to experience an increase in rice acreage until 1955 when the United States government allotted a maximum of 202,429 hectares of rice allowed to be grown in Arkansas (RJ Norman, personal communication). The rice acreage restrictions were removed in 1973, and Arkansas experienced a dramatic increase in acreage (Talbert & Burgos, 2007). As of 2018, Arkansas produced 577,733 hectares of rice. The state of Arkansas has consistently been the number one rice producing state in the country since 1973, accounting for 49% of all rice grown in the United States (Hardke, 2018). In Arkansas, rice is grown in 40 counties, predominantly in the eastern region of the state. Several counties in western Arkansas also contribute to the state's rice production (Hardke, 2018).

In Arkansas, rice is grown on several different soil textures. Fifty percent of rice grown in Arkansas is produced on a silt loam soil, followed by 44 percent on clay or clay loam soils, and 6 percent on sandy loam soils (Hardke, 2018). Because rice is able to grow in anaerobic conditions (Sheaffer & Moncoda, 2012), the majority of rice acres in Arkansas are grown in a flooded, or lowland, system, but furrow irrigated and alternate wetting and drying (AWD) or intermittent flooding are increasing in popularity with producers. Rice should be planted when the soil temperature is greater than 15.6 ˚C at a 10.2-cm depth. The University of Arkansas System Division of Agriculture recommends planting rice seed at depths ranging from 0.6 cm to 3.8 cm.

Rice in Arkansas is typically planted beginning at the end of March and planting can continue into June.

Rice Characteristics and Development

Rice is a grass and the leaf blades are sessile, narrow and flat. They attach to the sheath with a collar and have curved auricles with pubescence. The ligules may be acute, acuminate, or cleft (Moldenhauer et al., 2018). The leaf is comprised of the sheath and the blade and the leaf blade has parallel venation and a prominent midrib apparent on the underside of the leaf (Chang et al., 1965). The rice leaf blade is lanceolate in shape and the surface may be glabrous, intermediate, or pubescence may be present (Moldenhauer & Gibbons, 2003).

Rice has a panicle inflorescence made up of the base, the axis, primary branches, secondary branches, pedicel, and spikelet. In Arkansas, medium grains weigh 25-30 mg and long grains weigh 20-26 mg (Norman, personal communication). During the rice plant's life cycle there are three stages of growth: vegetative, reproductive, and grain fill. Vegetative growth occurs from the time the plant germinates until panicle initiation, or PI. Reproductive growth occurs from PI until heading. Grain fill occurs from heading until the rice plant reaches maturity. Rice grain yield is determined by multiple yield components, which are a measure of the plant's functioning throughout growth. The mechanisms that determine grain yield include the number of panicles per unit land area, the number of grains produced per panicle, and the weight of the individual grains. The number of panicles per unit land area are influenced during vegetative growth, or from germination to panicle initiation (PI). The average number of grains produced per panicle is affected during reproductive growth, or from panicle initiation to heading. The average weight of individual grains is determined from heading to maturity, or grain fill and maturation (Moldenhauer et al., 2018). Rice seed size and weight varies across cultivars (Hardke et al., 2018) and can affect the grain quality and value. Determining factors of grain size include the grain length, width, thickness, as well as the length to width ratio (Sun et al., 2013).

Cultivar Advancement

Throughout the history of rice production in Arkansas, there are four specific instances where rice grain yields saw substantial increases over short periods of time. These times were the implementation of new cultivars. In 1967 the University of Arkansas released the cultivar Starbonnet, which led to record rice grain yields being produced from 1969 to 1971. In 1983, Newbonnet was released, and in 1985 Newbonnet surpassed Starbonnet as the most widely grown cultivar, which resulted in state average rice grain yields increasing by 10 bushels per acre. Again, in the 1990s, Arkansas saw average grain yields gain 10 bushels per acre when the number of commercially available rice cultivars that were available to producers grew significantly. Arkansas has also seen dramatic yield increases from new technologies being initiated, such as hybrid cultivars. The introduction of Clearfield® (BASF Corporation, Research Triangle Park, NC 27709) rice in 2002 also contributed to the rise of average state yields. Clearfield® rice is resistant to the imidazolinone herbicides imazethapyr and imazamox, providing producers with a defense against yield reducing weeds (Hardke, 2018).

The majority of rice grown in Arkansas and across the Mid-South is of the race japonica, both tropical and temperate types. The types of rice grown in the Mid-South are primarily long-grain (tropical japonica) and medium-grain (temperate japonica) (Hardke, personal communication). Rice cultivars can be described as either an inbred, or pureline, variety or a hybrid cultivar. Pureline cultivars are produced by self-pollination breeding and selecting for specific traits. Hybrid cultivars are produced by crossing two genetically different parents (IRRI, 2007). First, a male-sterile line, which does not produce pollen, is crossed with a genetically similar male fertile, or maintainer, line. This process occurs to multiply the male-sterile line and ensure that the rice remains sterile. The male-sterile line is then bred to a genetically different fertile pollen plant, which results in the hybrid, or F1 generation, rice plant (Overett, 2005). Hybrid rice may be desired by producers because of heterosis, or hybrid vigor. Hybrid vigor can contribute to increased yields, greater plant productivity and have a superior ability to manage stresses, such as insects and disease (Yuan et al., 1989), as well as improved root architectural responses regarding water accessibility and nutrient uptake (De Bauw et al., 2019). It has also been shown that F1 hybrid rice may exhibit higher levels of heterosis during periods of increased rainfall and decreased solar radiation and when soil salinity levels may be elevated (Akita, 1988). Hybrid rice also produces more tillers, which can contribute to crop competitiveness against weeds. Due to the significant increase in tiller number per plant, hybrid cultivars are able to be seeded at lower rates than pureline varieties while still achieving canopy coverage and high yield potential. Hybrid cultivars exhibit more vigorous growth and greater adventitious root systems. Rice plants typically experience a decrease in number of grains per panicle when the number of panicles per unit area is increased, but this is not observed in hybrid cultivars (Shih-Cheng & Loung-Ping, 1980). Since first becoming available to producers in 2002-2003, and as of 2017, hybrid rice had grown to roughly 50 percent of all rice hectares in Arkansas (Hardke, 2018).

Row Spacing

Production Impact

The three methods Arkansas rice producers use to plant rice include dry drill-seeded, which is the most common planting practice and accounts for around 85 percent of rice planted, as well as dry broadcast-seeded at about 10 percent, and water broadcast-seeded, which makes up 5 percent of rice planted in the state (Hardke, 2018). Current recommended drill row widths for Arkansas rice range from 10 to 25 cm. The majority of producers in the state plant using 19-cm row spacing (Hardke & Mazzanti, 2019). Previous data has shown that 10-cm to 25-cm rice row spacings may not produce different grain yields and it would not be necessary to adjust seeding rates within that range. Row spacing is an important factor to consider when making overall crop management decisions. Ensuring a uniform stand density becomes much more important when rice row spacing is increased (Hardke et al., 2018). When rice is drill-seeded versus transplanted, the potential yield loss resulting from weed presence is greater due to the lack of a size difference between the rice and weed (Chauhan, 2012; Chauhan & Johnson, 2010). The rice is at a greater potential for lodging when row spacing is decreased due to tall or intermediate cultivars gaining too much height but, shorter or lodging resistant cultivars will result in higher grain yields when plant spacings are nearer (Jones & Snyder, 1987; Tanaka et al., 1964). To achieve maximum yield in early maturing cultivars, narrower row spacings are necessary due to the lack of vegetative growth (Yoshida, 1978).

Arkansas' current row spacing recommendations are based off of research conducted in 2004 and 2005. This work showed higher rice grain yields when planted on narrower 18-cm rows compared to wider 25-cm rows. Additionally, a broadcast seeding method was evaluated for one year. While 19-cm row spacings were most commonly utilized, 25-cm row spacing practice began to increase with Arkansas rice producers (Frizzell et al., 2006). These results demonstrated that 15- to 20-cm row spacings may result in optimal rice grain yields. (Hardke et al., 2018). An interest in 25-cm row spacing may have grown with producers due to the convenience and cost savings it would have allowed those planting rice and soybean (*Glycine max*). Although, the equipment investment could be significant for producers not currently utilizing equipment with 25-cm row spacing capability. Producers planting soybean may see an increase in grain yield when planting on narrower rows, such as 25 cm, versus wider row spacings such as 51 or 76 cm (Ashlock et al., 1996). Rice producers planting on heavier soils, such as a Sharkey clay, may find a benefit from a wider row spacing rather than a narrower spacing. Soil masses are much more likely to accumulate within the coulters on a narrower row spacing grain drill than on a wider spacing drill (Hardke et al., 2018; Frizzell et al., 2006), which would result in time and energy spent maintaining the functionality and cleanliness of the equipment. Increased producer interest in 25-cm row spacing may be due to these conveniences as well as the cost savings associated with rice and soybean being planted on identical row spacings (Frizzell et al., 2006).

Increases in light interception duration and total dry matter accumulation duration contribute to improved grain yields in soybean when planting using a narrower row spacing (Board et al., 1990). When row spacings are narrowed, it is shown that the plants intercept higher levels of radiation more rapidly. The plants are also able to reach the critical leaf area index sooner than if planting had occurred on a wider row spacing (Shibles and Weber, 1965; Counce, 1989). Factors specific to rice morphology and growth, such as tillering, will vary depending on cultivar and other cultural practices. Those effects can also be attributed to soil nitrogen (N) levels (Chandler, 1969; Jones and Snyder, 1987). Additionally, a response has been shown that plant nutrition, tillering, yield components, and grain yield in sub-optimal fertility conditions may be affected by a phosphorus (P) application, but not by a potassium (K) application (Reis et al., 2018). For studies conducted on multiple soil types with differing levels of available soil N, this results in dissimilar yield reactions across locations. This is indicative of a row spacing response due to excessive N uptake by the rice plant, which results in additional biomass production. This added plant tissue may lead to lodging, which in turn would result in a yield loss (Counce, 1989). Narrower row spacing is more ideal where soil N is lower rather than higher (Jones and Snyder, 1987; Tanaka et al., 1964).

Pest Management Impact

Rice pest management, specifically potential weed pressure and pathogens, will also be affected by cultural practices such as crop row spacing. In order for a plant disease to occur, three factors must be present. A virulent pathogen, a susceptible cultivar, and a favorable environment being exhibited simultaneously will result in an expression of the disease. If one of the three factors are removed, the pathogen will not be sustained (Wamishe et al., 2018). Amending cultural practices in order to mitigate crop disease is not a novel concept. It has been shown that a wider row spacing is optimal during periods of significant rainfall (Jones and Snyder, 1987; Tanaka et al., 1964) due to decreased solar radiation levels (Tanaka et al., 1964). Plant spacing may be used as a preventative cultural practice in regard to disease management (Howard, 1996).

It is imperative to implement additional weed management strategies to take selection pressure off of herbicides (Norsworthy et al., 2012), especially since technologies are already limited in rice. In Arkansas in 1990, barnyardgrass (*Echinochloa crus-galli*) populations were confirmed to be resistant to Group 7 photosystem II Inhibitors (e.g. propanil) and in 1999, multiple resistance was confirmed additionally with Group 4 synthetic auxins (e.g. quinclorac). Populations of red rice (*Oryza sativa* var. *sylvatica*) were confirmed to be resistant to Group 2 acetolactate synthase inhibitors (e.g. imazethapyr) in 2002. Again in 2008, barnyardgrass was confirmed to be resistant to Group 13 1-deoxy-D-xyulose 5-phosphate synthetase inhibitors (e.g. clomazone). Rice flatsedge (*Cyperus iria*) and smallflower umbrella sedge (*Cyperus difformis*) were confirmed to be resistant to Group 2 acetolactate synthase inhibitors (e.g. halosulfuron) in

2010. Junglerice (*Echinochloa colona*) was confirmed to have multiple resistances to Group 2 acetolactate synthase inhibitors and Group 7 photosystem II inhibitors (e.g. imazethapyr) in 2011. Yellow nutsedge (*Cyperus esculentus*) was confirmed in 2013 to be resistant to Group 2 acetolactate synthase inhibitors (e.g. halosulfuron) (Heap, 2020). Arkansas and Mississippi rice producers were surveyed and the results showed that only a limited number of producers were implementing cultural practices that could potentially reduce weed pressure (Norsworthy et al., 2013). When row spacings are decreased from 76-cm to 38-cm in corn (*Zea mays*), weed emergence and growth are able to be suppressed due to more rapid crop canopy closure (Teasdale, 1995).

Seeding Rate

Current University of Arkansas System Division of Agriculture seeding rate recommendations are approximately 323 seeds m^{-2} for pureline varieties and 118 seeds m^{-2} for hybrid cultivars. The appropriate seeding rate needs to be planted to attain greatest possible yield (Ottis, 2005). Rice seeding rates are dependent upon factors such as specific cultivar, seeding date, method of seeding, soil texture, and seedbed condition and preparation. The average rice planting date in the state varies from year to year due to environmental conditions and the seeding rates will be dependent upon the planting date. If planting occurs before April 5th, April 10th, or April 15th in South, Central, or North Arkansas, respectively, it is recommended that seeding rates be increased by 10 percent. After June 1st, it is recommended to increase the rice seeding rate by 20 percent regardless of location in the state. More time is necessary for rice to germinate, emerge, and reach the V5 growth stage when planted early. When planting late, it is important to select a cultivar that has performed well in seeding date studies. Typically, earlier planted rice surpasses late planted rice, but due to a wet and cool soil environment, stand density and uniformity may become an issue, which may lead to additional cost inputs. Seedling stress may also be higher for earlier planted rice, but it is also less likely to be subjected to severe blast (*Pyricularia oryzae*), kernel smut (*Neovossia horrida*; *Tilletia barclayana*), false smut (*Ustilaginoidea virens*) or bacterial panicle blight (*Burkholderia glumae*; *B*. *gladioli*). Late planted rice has the potential to experience temperatures that could lead to a reduction in grain yield, but also may be less likely to suffer from severe sheath blight (Hardke et al., 2018).

In Arkansas, seeding rate recommendations are based off of the dry drill-seeded planting method. Increased seeding rates are recommended for broadcast seeding methods. When rice is dry broadcast-seeded, it is recommended that seeding rates be increased by 20 percent and when rice is water broadcast-seeded it is recommended that seeding rates be increased by 30 percent. Different soil textures may require an adjusted seeding rate due to the fact that the recommendations are based on a loamy soils. While seeding rates are increased by 20 percent on clay soils, sandy soil seeding rates are not modified (Hardke et al., 2018). A good seedbed consists of a field that has a smooth surface and has the ability to be well drained and managed (Hardke et al., 2018). When no-till practices have been implemented, the seedbed conditions are considered fair and the seeding rate should be increased by 10 percent. When seedbed conditions are considered poor the seeding rate should be increased by 20 percent (Hardke et al., 2018; Hardke & Mazzanti, 2020). Additionally, when rice is planted in a field that has grape colaspis (*Colaspis brunnea*) larvae present, seeding rates should also be increased, as well as insecticide seed treatments and cultural practices may be necessary to implement (Hardke et al., 2018; Lorenz et al., 2018).

Seeding rate is a determining factor of establishing an appropriate stand of rice (Hardke et al., 2018). Optimum stand density for conventional varieties is 108 to 215 rice plants m^{-2} and

65 to 108 plants m^{-2} per square meter for hybrid cultivars (Hardke et al., 2018). When the stand density is above optimum, the rice is at an increased risk of disease. Lodging potential is also greater due to increased plant height (Hardke et al., 2018). Because of the high plant density, the rice does not have space available for additional lateral growth so instead they grow taller (Hardke, personal communication). In high-yielding cultivars, such as taller plants with a greater number of panicles, lodging tendency is increased (Setter et al., 1997). It has been shown that direct-seeded rice is at an increased risk of lodging due to the roots not being as well secured when compared to transplanted rice (Setter et al., 1994; Chang and Loresto, 1985).

An understanding of the influences of stand establishment are important for the life of the crop (Richardson et al., 2001). When the rice stand density is suboptimal, uniformity becomes critical (Hardke et al., 2018). In turfgrasses, when stand establishment is delayed or unsuitable, issues may persist for the remainder of that crop (Richardson et al., 2001). Additional weed pressure may become an issue and additional N applications may be needed to amplify tillering. It was observed that lower seeding rates resulted in greater yields when the N level was higher (Jones and Snyder, 1987; Wells and Faw, 1978). This demonstrates that specific cultivars planted at lower seeding rates have the ability to generate additional biomass to account for gaps within the crop canopy (Ottis, 2005). These cultivars are compensating added plant biomass in order to regain the potential yield lost with the lower plant density. Yield will also not be reduced when seeding rates are increased due to lowered grain fill (Gravois and Helms, 1992; Jones and Snyder, 1987; Ottis, 2005). Conversely, the plants seeded at higher rates will not experience yield loss due to the grain fill compensation.

Increased seeding rates can be implemented as a cultural practice to encourage crop competition and to aid in reducing potential weed pressure (Norsworthy et al., 2012), but raise production and input costs for the producer (Norsworthy et al., 2012; Walsh & Powles, 2007). The possibility of herbicide resistance is lessened when weeds are not allowed to emerge and in turn not reproduce and contribute to the soil seedbank (Norsworthy et al., 2012; Norsworthy et al., 2007b; Neve et al., 2011a). Alternatively, many rice producers may be leery of planting at a reduced seeding rate due to the potential of stand issues occurring. If a reduced seeding rate was planted and emergence issues occurred, resulting in a stand below current threshold recommendations, it may become necessary to replant, adding an additional cost to the producer (Ottis, 2005). Cultivars should be chosen that possess outstanding seeding vigor and seed treatments should be used that allow for rapid and unvarying stand establishment (Roberts et al., 2018). In addition to weed management, most of the cultural practices used also support increased crop yields (Norsworthy et al., 2012; Howe and Oliver, 1987; Norsworthy and Frederick, 2005; Norsworthy and Oliver, 2001).

Plant Spatial Density

When rice is drill-seeded it is placed in rows, and unlike transplanted rice it is impossible to ensure equidistant plant spacing. When the plant stand is uniform and even-aged, high yields should be achievable due to the decreased number of suppressed and fairly ineffective plants (Counce et al., 1989). With the current dry drill-seeding planting practice, when row spacings or seeding rates are modified, interplant competition is not consistent. In order to achieve increased interplant competition in wider row spacings, more seeds must be planted within the row (Jones and Snyder, 1987). In another grass crop such as corn (*Zea mays* L.), when emergence and plant spacing are uneven, yield can be reduced. It is recommended that when the seed is planted, it is spaced as uniformly as possible. Maximum corn yields can be achieved when the seed is planted uniformly at the appropriate depth and when spacing between the seed is uniform (Ross et al., 2020). When crops are planted in rows, the number of times required for equipment to pass through the field can be reduced, but the time for the crop to obtain full canopy coverage will be greater (Connor et al., 2011). When specific and uniform plant placement is not feasible, discrepancies in yield may occur. Thus, allotting space for each plant becomes important (Mead, 1966).

A plant's competitive ability has been described as the capability of a specific genotype to produce acceptable yields and effectively contend for nutrients and soil water when it is bordered by alike or disparate genotypes (Francis, 1981). There have been four types of intergenotypic competition described, under compensation, complementary compensation, neutral or no compensation, and over compensation. Under compensation takes place when the yield increase of the superior competitor is lower than the yield decrease of the inferior competitor. Complementary compensation takes place when the yield increase of one competitor is equal to the yield decrease of the other competitor. When the competitors do not actually show competitive effects and the combination yield is equivalent to the average of the competitors, neutral compensation is taking place. Over compensation takes place when the yield increase of one competitor is greater than the yield decrease of the other competitor (Schutz and Brim, 1967). Under compensation has been shown to occur between two different rice cultivars planted in alternating rows. In that planting arrangement, the grain yield was 126% of the average when each cultivar was allowed to grow in a separate environment, or cultivar (Roy, 1960), but it has also been shown that rice yields not be influenced by a lower seeding rate as long as hybrid seed is planted uniformly and efforts are made to reduce stressors (Chauhan & Opeña, 2013).

Intraspecific competition involves one species, or within a crop. Interspecific competition happens between species, such as the interaction between a crop plant and a weed. Crop competitiveness regarding weed competition can be described two ways, having the capability to be competitive with weed species and restricting weed biomass and seed output, as well as not experiencing a reduction in yield when in competition with weed species (Callaway, 1992). Rice grain yields can be lowered from 10 percent with eclipta (*Eclipta prostrata*) and to 82 percent with weedy rice present. Multiple factors determine the impact weed presence will have on a rice crop including, weed species, weed density, rice cultivar being grown, and other cultural practices being implemented. Rice plant architecture varying across cultivars results in differences in competitive ability (Scott et al., 2018).

Rice tiller grain yield is significant to the overall yield of the rice crop. The order the tillers emerge is a determining factor of yield for a specific culm. Additionally, higher yields are observed in earlier emerging tillers than in later emerging tillers (Counce et al., 1996). Because rice exists as a tillering plant, a population is not considered homogenous (Wu et al., 1998). Plant density, as well as the cultivar grown have both been shown to influence tillering (Wu et al., 1998), but when tillering is determined it is most affected by plant density (Counce et al., 1992; Schnier et al., 1990). When the plant density is greater, the tiller density will be decreased (Hoshikawa, 1989). Thus, when the plant population is suboptimal, tillering can influence yield components to still achieve acceptable rice grain yields (Wu et al., 1998).

The hypotheses of this research are that a crossed-planting arrangement will produce higher rice grain yields than a typical single direction arrangement and that an 8-cm row spacing will increase rice grain yield when compared to wider row spacings. The objectives of this research are to assess the impact of rice planting arrangement on plant density, canopy coverage, grain yield, and milling yield and to evaluate the impact of rice row spacing on stand density, grain yield, and milling yield.

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CHAPTER TWO: Effect of Crossed Planting Arrangement on Grain Yield and Canopy Coverage of Rice (*Oryza sativa* L.)

Abbreviations:

RREC – Rice Research and Extension Center; NBPT – n-butyl-thiophosphoric triamide; NEREC – Northeast Research and Extension Center; LAI – Leaf area index

Core Ideas:

- Increasing grain yield is possible under crossed-planting arrangement.
- Planting arrangement did not influence canopy coverage.
- Potential to reduce hybrid seeding rate when cross-planting, but additional seeding rate studies are necessary.

Abstract

In Mid-South rice (*Oryza sativa* L.) production, producers primarily utilize a dry, drill-seeded, or direct-seeded planting practice. With these planting practices there is no way to ensure precise and uniform seed placement. Implementing unconventional planting arrangements may allow for reduced seeding rates while maintaining or increasing yield. Experiments were conducted in the summer of 2019 and 2020 at the Rice Research and Extension Center (RREC) near Stuttgart, AR on a DeWitt silt loam soil and at the Northeast Research and Extension Center (NEREC) near Keiser, AR on a Sharkey clay soil to determine the effects of a crossed planting arrangement on stand density, canopy formation, and grain yield. The experiment was set up as a two-factor factorial randomized complete block design with four replications with the first factor being planting arrangement and the second factor being seeding rate. The pureline cultivar Diamond was planted at the seeding rates of 108, 215, 323, 431, and 538 seeds m^{-2} and 43, 75,

108, 140, 172 seeds m^{-2} for the hybrid cultivar RiceTec XP753. The first planting arrangement was a straight planted pass (normal) and the second arrangement consisted of two passes with the second pass being perpendicular to the first pass (cross). In this experiment, the pureline Diamond and the hybrid XP753 were not compared statistically. For stand density in Diamond, a normal planting arrangement resulted in a greater planting arrangement than a crossed arrangement ($p = 0.0201$), but planting arrangement did not influence stand density in XP753. For each cultivar, canopy formation was only influenced by seeding rate ($p < 0.0001$; $p < 0.0001$). In Diamond and XP753, a cross planting arrangement resulted in higher rice grain yields when compared to a normal planting arrangement ($p < 0.0001$; $p < 0.0001$). There was a planting arrangement by seeding rate interaction for total white rice in Diamond. This resulted in a crossed planting arrangement at 431 seeds m^{-2} leading to the highest total rice milling yield. Results indicate that a shift in planting to a crossed practice may result in an increase in grain yield, although it is not yet known the economic impact this practice may have on production. While additional research is necessary, the lack of a seeding rate impact on canopy formation was surprising, although, a crossed planting arrangement may lead to a potential decrease in hybrid seeding rates.

Introduction

In Arkansas, rice seeding methods include dry drill-seeding, dry broadcast seeding, and water broadcast seeding (Hardke & Mazzanti, 2021). In 2019, 84% of all rice grown was dry drill, or direct-seeded (Hardke, 2020). When direct-seeding rice, dry rice seed is drilled in rows into a dry soil environment (Farooq et al., 2011). Another grass crop with comparable planting practices to rice is wheat (*Triticum aestivum*). The ability of these crops to tiller allows for maximum yield to be achieved without necessarily requiring precise seed spacing and uniformity. The majority of cereal crops are planted using traditional grain drills (Marburger & Lofton, 2017) unlike corn (*Zea mays* L.) which is typically planted using precision equipment to increase the likelihood of uniform seed placement.

The goal of water-seeding rice fields is to try to achieve even plant spacing, where each plant is as close to equidistant from one another as possible. With this planting method, the seed is soaked in water, pregerminated and then flown onto the flooded field where the seed will sink and land on the surface of the soil (Espino, et al. 2018). The final stand is established during this time that the seeds are settling on the soil surface. Ensuring an adequate plant density is critical to achieving maximum yield potential (Rutger & Brandon, 1981). Research has shown that yield was not reduced when the seedling stand ranged from 129-495 plants m^{-2} (Miller et al., 1991).

While possible in transplanted rice, equidistant plant spacing is currently unattainable with commercial equipment when direct-seeding rice using traditional grain drills. When the number of comparatively inefficient and repressed plants is low, yields should increase due to overall uniformity across the field (Counce et al., 1989). When seeding rates or row spacings are modified, the interplant competition will differ considerably. Seeding rates must be increased to attain higher levels of interplant competition when planting on wider row spacings (Jones & Snyder, 1987). In wheat, a tillering grass crop similar to rice, it is possible for yield to be lost when stand is reduced below an acceptable level despite equal plant spacing and growth opportunities (Wilson & Swanson, 1962). In order to achieve maximum yield potential in wheat, the physiological basis must be understood (Fischer, 2007). Crop breeding and management rely on physiological improvements to proceed. Rice, like wheat, must continue to be bred and studied in order for progress to be occurring and producers to remain profitable.

Crops that are planted in rows take longer to achieve full canopy coverage, but a fewer number of trips can be taken across the field (Connor et al., 2011). Allocating specific space for each plant in the field is crucial due to the potential for disparities in yield taking place. This may result when it is not possible to achieve unvarying and precise plant placement (Mead, 1966). Competitive ability is characterized in plants when distinct genotypes are capable of achieving satisfactory yields and efficiently challenging others for moisture and nutrients and having an advantage over similar and different genotypes (Francis, 1981). Intergenotypic competition includes under compensation, complementary compensation, neutral or no compensation, and overcompensation. When the yield decrease of the inferior competitor is less than the yield increase of the superior competitor, under compensation is occurring. When the decrease of one of the competing plants is equal to the increase of the other competing plant, complementary compensation is happening. Neutral compensation is occurring when the combination yield is parallel to the mean of the rival plants and when competing effects are not displayed. When the yield increase of one competing plant is higher than the yield decrease of the other competing plant, overcompensation is taking place (Schutz and Brim, 1967).

Two pureline rice cultivars resulted in 126% of the mean yield when allowed to grow in individual settings, or planted as a single cultivar, but when planted in rows that were alternating cultivars, responded with under compensation (Roy, 1960). Additional studies have exhibited that if hybrid rice seed is planted uniformly and factors that would allow for stand reduction are controlled, seeding rate may be reduced and can be attributed to the much greater tillering potential of hybrid vs. pureline cultivars (Chauhan & Opeña, 2013).

The relationship between a weed and the crop is described as interspecific competition and when the relationship is inside the crop, intraspecific competition is occurring. When crops are competing with weed species, characteristics such as height, high leaf area index (LAI), and rapid canopy formation appear to be generally related to heightened weed tolerance (Callaway, 1992). A rice plant's opportunistic capability can vary greatly across cultivars as plant architecture will not be the same. Cultural practices, weed density, weed species present, and rice cultivar all contribute to the effects of weed proximity. Yield losses in rice can range from 10% when eclipta (*Eclipta prostrata*) is present all the way to 82% with weedy rice in the field (Scott et al., 2018).

Due to tillering, rice plant populations are not regarded as homogenous (Wu et al., 1998). Tillers that emerge later have been shown to yield lower than tillers that emerge earlier. For an individual culm, tiller emergence order is an influential component for yield and the tiller grain yield is meaningful to the general yield (Counce et al., 1996). A substantial impact on tillering has been observed based on the selected cultivar and the density at which the rice is planted. Changes in rice cultivar and plant density result in the varying ability to compensate (through tillering and other factors) and attain adequate yields even when there is a poor rice stand in the field (Wu et al., 1998). It has been shown that when the concentration of plants is higher, the concentration of tillers is lower (Hoshikawa, 1989) and that plant density impacts tillering (Counce et al., 1992; Schnier et al., 1990).

Rice planted at a high density are more prone to disease as well as lodging from the increased plant height and lack of airflow through the dense canopy. When verifying a suitable plant stand for a rice crop, a deciding component is the seeding rate (Hardke et al., 2018). Rice plants will increase vertical growth when plant density is greater due to the lack of obtainable area and increased interplant competition for light (Hardke, personal communication). Rice plants with increased height and more panicles due to competition or increased tillering may also be at a greater risk of lodging (Setter et al., 1997).

Due to the novelty of cross planting, as far as it is known no prior research exists using this practice in rice. However, as precision planting equipment evolves and the ability to singulate rice seed draws closer, there is a need to understand rice responses to planting arrangement. The objective of this research was to determine the effects of rice planting arrangement and seeding rate on stand density, canopy coverage, grain yield, and milling yield.

Materials and Methods

Field experiments were conducted in 2019 and 2020 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, AR on a DeWitt silt loam (Fine, smectitic, thermic Typic Albaqualfs) and at the Northeast Research and Extension Center (NEREC) near Keiser, AR on a Sharkey silty clay (very-fine, smectitic thermic Chromic Epiaquerts). The fields are in a rice/soybean (*Glycine max*) rotation to avoid a monoculture. The treatment structure was a two-factor factorial where the first planting arrangement was a single pass in one direction (normal) and rows were parallel to one another. The second planting arrangement required three cross passes to cover the whole area of the first pass. The row spacing for each planting arrangement was 19 cm. Two rice cultivars were included in this study, a pureline variety (Diamond) and a hybrid (XP753) (RiceTec Inc., Alvin, TX). These cultivars were choses as they are the highest yielding and most widely grown conventional variety and hybrid, respectively. Diamond was planted at seeding rates of 108, 215, 323, 431, and 538 seeds m^{-2} and XP753 was planted at seeding rates of 43, 75, 108, 140, and 172 seeds m^{-2}. The treatments were replicated four times. The plot size was 5 m long by 1.5 m wide and was planted using an 8-row Almaco© (Almaco, Nevada, IA) cone drill on 19 cm spacing.

Following rice emergence, stand count data were collected by counting the number of seedlings emerged within 0.093 m^{-2} at three random locations within each plot. Photographs were taken of each plot three times at approximately one week apart beginning when the rice reached the V4 to V5 (Counce et al., 2000) growth stage until full canopy coverage was achieved. Two sets of images were taken before the permanent flood was applied and the third image set was taken after the permanent flood was applied. An Apple© (Apple Inc., Cupertino, CA) iPad (6th generation) was positioned higher than 60 cm over the canopy to capture images. Images for each plot within a study were captured on the same day. Canopy coverage was analyzed on each photograph using Turf Analyzer (turfanalyzer.com/turf-analyzer). Threshold setting were adjusted to achieve the most accurate analysis for each image set. A single preflood N application was made at the RREC and NEREC locations when the rice reached the V5 growth stage and was applied at rates of 146 kg N ha^{-1} and 179 kg N ha^{-1}, respectively. The N applications were made in the form of urea (460 g N kg^{-1}) treated with n-butyl-thiophosphoric triamide (NBPT), a urease inhibitor. These applications, as well as all other cultural practices, followed current University of Arkansas System Division of Agriculture recommendations (Roberts et al., 2018).

When the rice plants reached maturity, the center 76 cm by the length of each plot were harvested using a Wintersteiger Classic plot combine (Wintersteiger, Ried im Innkreis, Austria), and grain moisture content and weight were determined. Rice grain yield was expressed on a kg ha^{-1} basis and adjusted to 120 g H_20 kg^{-1} moisture. A 100-g sample from each plot was milled using a PAZ-1 laboratory rice mill (Zaccaria USA, Anna, TX) to determine the milling yield, denoted as percent head rice (%HR, whole kernels, head rice yield) and percent total white rice (%TR, total rice yield).

Statistical Analysis

All data for this experiment were analyzed using the PROC GLIMMIX procedure and analysis of variance statistics with SAS version 9.4 (SAS Institute Inc., Cary, NC). Planting arrangement and seeding rate and their interactions were considered as fixed effects in the model. Soil texture had no effect on the results so site year was considered a random effect with four levels. The means for data were separated using Fisher's protected least significant difference test at the 5% level of significance.

Results

Diamond Stand Density

In Diamond, there were no planting arrangement by seeding rate interactions for stand density (Table 2.1). The normal planting arrangement resulted in greater stand density compared to the cross-planting arrangement (Table2.2). The normal planting arrangement improved rice stand density to 220 plants m^{-2} from 206 plants m^{-2} with the cross-planting arrangement. Typically, plant emergence may be greater where there is a higher number of plants in a given area. If the cross-planting arrangement plants have more equal space, this may explain why the normal planting arrangement resulted in greater stand density, due to improved emergence. Seeding rate impact on stand density was linear with lower seeding rates each subsequently resulting in lower plant stand density (Table 2.3). With conventional varieties, stand density recommendations range from 107-215 plants m^{-2}. The stand density resulting from the 215 plants m^{-2} rate was the only rate resulting in a stand density within the recommended range. While the rate of 323 seeds m^{-2} is the current recommendation for Diamond, this rate resulted in a stand density that exceeds current recommendations. in this study. The current recommended seeding rate should not be exceeded, due to the greater risks of disease and lodging (Hardke et al., 2018) as well as increased input costs associated with higher seeding rates. These results are consistent with Frizzell et al. (2006) where stand density increased as seeding rate increased.

Diamond Canopy Coverage

There were no image timing interactions, therefore canopy coverage was averaged across all timings (Table 2.1). For canopy coverage there was no planting arrangement by seeding rate interaction for Diamond. The main effect of seeding rate had a significant effect on canopy coverage. The 538 seeds m^{-2} rate resulted in the greatest percent canopy closure (Table 2.3). Each subsequently lower seeding rate resulted in lower percent canopy cover. Similar to stand density, canopy coverage increased with seeding rate; however, a fivefold increase in seeding rate only resulted in a two old increase in canopy coverage. These results suggest that gains in canopy coverage do not increase as quickly as stand density with increased seeding rates, and the benefits of increased canopy coverage need to be weighed against the increasing seed cost.

Diamond Grain Yield

For rice grain yield in Diamond, there was no planting arrangement by seeding rate interaction, only the treatment main effects of arrangement and seeding rate (p=0.0127) (Table 2.1). The cross planted arrangement produced 581 kg ha^{-1} greater rice grain yield than the normal arrangement (Table 2.2). When comparing Diamond seeding rate effects on rice grain yield, the 538 seeds m^{-2} resulted in the highest overall rice grain yield and produced greater yields than the 215 and 108 seeds m^{-2} rates (Table 2.3). The 323 and 431 seeds m^{-2} rates resulted in higher grain yields compared to the 108 seed m^{-2} rate.

Diamond Milling Yield

In Diamond, there was a planting arrangement by seeding rate interaction for total rice (Table 2.1). The cross-planting arrangement planted at 431 seeds m^{-2} resulted in the greatest total white rice yield and the 538 seeds m^{-2} planted in a normal arrangement resulted in the lowest total white rice yield (Table 2.4). Seeding rate had an effect on head rice yield for Diamond, where the 108 seeds m^{-2} rate resulted in the greatest head rice yield compared to the 323 and 538 seeds m^{-2} rates (Table 2.3). Results from Hardke et al. (2017) show where a seeding rate increase resulted in a decrease in head rice. These results are surprising due to the fact that Hardke et al. (2015) showed results where lower seeding rates subsequently resulted in lower head rice yield as well as lower total white rice yield. These conflicting results as well as milling issues Arkansas rice producers currently face do indicate the need for further milling quality research to be conducted in various cultivar and management scenarios.

XP753 Stand Density

In XP753, there were no seeding rate by planting arrangement interactions for stand density (Table 2.1). The 172 seeds m^{-2} rate resulted in greater stand density than all other seeding rates (Table 2.5). While the 108 and 75 seeds m^{-2} rates were not different, they were greater than the 43 seeds m^{-2} rate. The same general seeding rate and stand density relationship trend was observed with XP753 as was observed with Diamond. Rates of 75 to 172 seeds m^{-2} resulted in acceptable stand densities, within the recommended range. This suggests that seeding rates lower than currently recommended can achieve stand densities within the recommended range. Data from additional seeding rate studies should be considered before adjusting seeding rate.

XP753 Canopy Coverage

There was no planting arrangement by seeding rate interaction for canopy coverage in XP753 (Table 2.1). The main effect of seeding rate had a significant effect on canopy coverage. For percent canopy cover, the 172 seeds m^{-2} rate produced was greater than all other rates except 140 seeds m^{-2}(Table 2.5). In general, as seeding rate increased, canopy coverage increased. Similar to Diamond, canopy coverage did not increase as quickly as stand density with increasing seeding rates. While not directly compared in this study, seeding rates used for XP753 and Diamond resulted in similar canopy coverage.

XP753 Grain Yield

For XP753 grain yield, there was no planting arrangement by seeding rate interaction, only treatment main effects (Table 2.1). Cross planted plots resulted in 488 kg ha^{-1} greater rice grain yield than a normal planting arrangement (Table 2.6). Seeding rates of 75 seeds m^{-2} and above resulted in similar grain yields, all of which were greater than the 43 seeds m^{-2}(Table 2.5). These results are not unexpected as seeding rates of 75 -172 seeds m^{-2} produced stand densities within the current recommended range for XP753.

XP753 Milling Yield

Planting arrangement in XP753 had a significant main effect on total white rice (Table 2.1) where a normal planting arrangement resulted in higher total white rice yield than a cross planting arrangement (Table 2.6). As seeding rate increased head rice yields decreased. The 43 seeds m^{-2} rate resulted in greater head rice than the 108, 140, and 172 seeds m^{-2} rates (Table 2.5). Percent head rice for all seeding rates was greater than the industry standard of 55%. As percent head rice increases above 55%, producers are paid a premium. While these differences in percent head rice may appear small, gains or losses do affect producer profits.

Discussion

In order to recommend an added input cost associated with a cultural practice such as cross planting, there must be justification that yield is increased to cover the added cost or that there is opportunity to reduce costs in other areas, such as seed or reduced herbicide inputs. The purpose of the studies conducted at the RREC and NEREC in Arkansas were intended to determine if there were advantages from cross planting. Findings from this study indicate that there is potential to improve rice grain yield when cross planting rice compared to a normal planting arrangement in a pureline and hybrid cultivar. While the two cultivars were not compared statistically, there were consistent trends observed. In the cross-planted scenario, both cultivars produced higher grain yields than in a normal planting pattern. Also, the respective seeding rates for each cultivar generally followed the same stand density trend. The linear trend observed in Diamond seeding rate effects on grain yield are typical for seeding rate studies but does not lead to the conclusion that seeding rates could further be reduced when cross planting, but there may be potential for a seeding rate reduction when cross planting in hybrids. Further research is necessary to determine if this is a feasible option. Overall in Diamond, the normal planting arrangement resulted in greater stand density than the cross planted arrangement. In XP753, the 172 seeds m^{-2} rate resulted in greater plant density than all other seeding rates, which is not unusual for seeding rate studies, but the 75 and 108 seeds m^{-2} rates did not result in different plant stands. The potential for lodging to occur may be a disadvantage of cross planting, although, no lodging was observed in this study. Ultimately, the practical implications of this planting method will be dependent upon the economic benefit or lack thereof. If a producer could confidently reduce seeding rates or a herbicide application there may be a benefit. In order to offset the additional cost of machinery, fuel, and labor, the yield increase or associated input cost savings would need to be greater than the expense of the additional trip across the field while planting.

Interestingly, planting arrangement did not have a significant effect on canopy coverage in rice, which would have the potential to decrease time to full canopy formation. In Diamond, canopy coverage did show an increasing trend as did stand density. For canopy coverage in XP753, the 172 seeds m^{-2} seeding rate resulted in greater canopy coverage than the 108, 75, and 43 seeds m^{-2} rates. In Diamond, there was a planting arrangement by seeding rate interaction for total white rice of milling yield, where 431 seeds m^{-2} in a cross-planting arrangement resulted in highest total white rice milling yield. Head rice yield in Diamond varied across seeding rates and no real trend is apparent. For XP753, total white rice yield was greater when a normal planting arrangement was used when compared to a cross planted arrangement. A slight trend could be inferred in XP753 head rice where milling yield decreases as seeding rate increases.

In order for adoption of a cross planted practice to be acceptable, it must make sense economically for the producer. Per 0.405 ha^{-1} a producer incurs an estimated cost of $12.24 for each planted pass (Watkins, 2021). Certainly, a second pass will double planting costs, however, increased time spent planting may be of equal or greater importance. With the value of time during planting season, it may not be feasible for producers to spend twice as much time planting rice, especially with large hectares and multiple crops. Field preparation and chemical applications timing also will play a role in time and decisions surrounding incorporating a cross planting practice.

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Tables

Table 2.1. The p-values from analysis of variance for rice stand density, canopy coverage, grain yield, and milling yield from 2019 and 2020 at the RREC and the NEREC.

	Cultivar									
	Diamond					XP753				
	Prob. > F									
Source	Stand Density	Canopy Coverage	Grain Yield	Total Rice	Head Rice	Stand Density	Canopy Coverage	Grain Yield	Total Rice	Head Rice
Arrangement	0.0201*	0.1883	<.0001*	<.0001*	0.0916	0.8428	0.2561	<.0001*	0.0429*	0.2137
Rate	<.0001*	<.0001*	0.0127*	0.5167	0.0241*	<.0001*	<.0001*	<.0001*	0.6405	0.0007*
Arrangement × Rate	0.3842	0.6029	0.9084	<.0001*	0.9434	0.5300	0.9552	0.9598	0.2620	0.5483

[a] P-values within columns denoted by asterisks indicate significance.
[b] RREC: Rice Research and Extension Center.
[c] NEREC: Northeast Research and Extension Center.

Table 2.2. Effect of Diamond planting arrangement on stand density and grain yield averaged over 2019 and 2020 at the RREC and the NEREC.

Planting Arrangement	Stand Density (plants m^{-2})	Grain Yield (kg ha^{-1})
Normal	220 a	9552 b
Cross	206 b	10133 a

[a] Means followed by the same letter within a column are not significantly different using a Fisher's protected LSD at α=0.05.
[b] Normal planting arrangement equal to traditional 19 cm straight planted pass.
[c] Cross arrangement equal to perpendicular 19 cm passes.
[d] RREC: Rice Research and Extension Center.
[e] NEREC: Northeast Research and Extension Center.

Table 2.3. Effect of Diamond seeding rate averaged over row orientation on stand density, canopy coverage, grain yield, and head rice averaged over 2019 and 2020 at the RREC and the NEREC.

Seeding Rate (seeds m^{-2})	Stand Density (plants m^{-2})	Canopy Coverage (%)	Grain Yield (kg ha^{-1})	Head Rice (%)
108	90 e	11.0 e	9539 c	62.0 a
215	157 d	17.5 d	9716 bc	61.4 ab
323	244 c	20.1 c	9948 ab	60.8 b
431	307 b	23.1 b	9974 ab	61.2 ab
538	376 a	25.8 a	10080 a	60.8 b

[a] Means followed by the same letter within a column are not significantly different using a Fisher's protected LSD at α=0.05.
[b] RREC: Rice Research and Extension Center.
[c] NEREC: Northeast Research and Extension Center.
[d] Canopy coverage was an average of three assessment dates.

Table 2.4. Planting arrangement by seeding rate interaction effect in Diamond on total rice milling yield averaged over 2019 and 2020 at the RREC and the NEREC.

Planting Arrangement	Seeding Rate (seeds m^{-2})	Total Rice %
Normal	108	70.3 de
	215	70.2 f
	323	70.2 e
	431	70.4 d
	538	70.1 g
Cross	108	70.3 e
	215	70.6 b
	323	70.5 c
	431	70.7 a
	538	70.4 d

[a] Means followed by the same letter within a column are not significantly different using a Fisher's protected LSD at α=0.05.
[b] Normal planting arrangement equal to traditional 19 cm straight planted pass.
[c] Cross arrangement equal to perpendicular 19 cm passes.
[d] RREC: Rice Research and Extension Center.
[e] NEREC: Northeast Research and Extension Center.

Table 2.5. Effect of XP753 seeding rates averaged over row orientation on stand density, canopy coverage, grain yield, and head rice averaged over 2019 and 2020 at the RREC and the NEREC.

Seeding Rate (seeds m^{-2})	Stand Density (plants m^{-2})	Canopy Coverage (%)	Grain Yield (kg ha^{-1})	Head Rice (%)
43	33 d	10.7 d	10539 b	58.4 a
75	64 c	15.4 c	11504 a	57.5 ab
108	65 c	20.2 b	11716 a	57.2 b
140	89 b	22.8 ab	11655 a	56.6 bc
172	104 a	24.7 a	11761 a	56.2 c

[a] Means followed by the same letter within a column are not significantly different using a Fisher's protected LSD at α=0.05.
[b] RREC: Rice Research and Extension Center.
[c] NEREC: Northeast Research and Extension Center.
[d] Canopy coverage was an average of three assessment dates.

Table 2.6. Effect of XP753 planting arrangement on grain yield and total rice averaged over 2019 and 2020 at the RREC and the NEREC.

Planting Arrangement	Grain Yield (kg ha^{-1})	Total Rice (%)
Normal	11174 b	71.9 a
Cross	11662 a	71.5 b

[a] Means followed by the same letter within a column are not significantly different using a Fisher's protected LSD at α=0.05.
[b] Normal planting arrangement equal to traditional 19 cm straight planted pass.
[c] Cross arrangement equal to perpendicular 19 cm passes.
[d] RREC: Rice Research and Extension Center.
[e] NEREC: Northeast Research and Extension Center.

Figures

Figure 2.1. Rice planted in normal 19 cm row spacing.

Figure 2.2. Rice planted in cross planted arrangement in 19 cm row spacing.

CHAPTER THREE: Row Spacing and Seeding Rate Effects on Rice (*Oryza sativa* L.) Grain Yield

Abbreviations: RREC – Rice Research and Extension Center; NBPT – n-butyl-thiophosphoric triamide; NEREC – Northeast Research and Extension Center

Core Ideas:

- Overall, current row spacing recommendations are adequate to achieve acceptable yields.
- In XP753, the rice produced higher grain yield in the 19 and 8 cm row spacings than the 38 cm row spacing.
- In Diamond, 215-538 seeds m^{-2} rates at 8 and 19 cm row spacings produced higher grain yields than all seeding rates for the 38 cm row spacing.
- Current seeding rate recommendations are adequate to achieve acceptable yields.

Abstract

In rice (*Oryza sativa* L.) production in Arkansas and across the Mid-South, producers most commonly direct-seed, or drill-seed rice. Current rice row spacing recommendations in Arkansas include 10- to 25-cm row spacings, but the majority of producers plant on 19-cm row spacings. Experiments were conducted in the summer of 2019 and 2020 at the Rice Research and Extension Center (RREC) near Stuttgart, AR on a DeWitt silt loam soil and at the Northeast Research and Extension Center (NEREC) near Keiser, AR on a Sharkey clay soil to evaluate multiple row spacings and seeding rates. The experiment was set up as a two-factor factorial randomized complete block design with 4 replications with the first factor being row spacing and the second factor being seeding rate. The pureline cultivar Diamond was planted at the seeding rates of 108, 215, 323, 431, and 538 seed m^{-2} and the hybrid cultivar XP753 at 43, 75, 108, 140,

172 seeds m^{-2}. Three row spacings, 8, 19, and 38 cm, were evaluated in each cultivar at each seeding rate. For XP753, the 8 and 19 cm row spacings had higher yields than the 38 cm row spacing. For Diamond the 8 and 19 cm row spacings planted at 215 seeds m^{-2} and above all yielded greater than the other row spacing and seeding rate combinations. Overall, the results of this study agree with current row spacing and seeding rate recommendations; however, lower seeding rates than currently recommended can be viable.

Introduction

In Arkansas direct-seeded, delayed-flood rice production, there is limited research on the effects of row spacing on hybrid rice cultivars. Some Arkansas studies have indicated that optimal rice row spacings for varieties and hybrids range from 15 to 25 cm (Frizzell et al., 2006; Frizzell et al., 2007) but 19 cm is the most utilized row spacing by Arkansas producers (Hardke and Mazzanti, 2019). When rice row spacing is widened, achieving uniform stands becomes increasingly critical (Hardke et al., 2018) due to the plant density being less than in a narrow row spacing. This results in more space between plants, leaving increased opportunity for variation within the row. When row spacings are narrower, lodging resistant and shorter cultivars need to be planted because the rice has an increased risk to lodge at narrower row spacings because of the increased plant height (Jones and Snyder, 1987; Tanaka et al., 1964). Due to the decrease in vegetative biomass production, narrower row spacings are essential when planting early maturing cultivars to ensure that light capture is maximized (Yoshida, 1978).

The most recent row spacing research in Arkansas was conducted in 2004 and 2005 (Frizzell et al., 2006), but with the adoption of new cultivars and mechanical improvements it would be beneficial to reevaluate rice row spacing recommendations. The results from 2004 and 2005 showed that 18-cm row spacings would result in greater rice grain yields than wider 25-cm row spacings. Row spacings of 25-cm are still used, but 19-cm spacings are still the most popular with Arkansas rice producers. Because many producers will also be planting soybean (*Glycine max*), 25-cm row spacings would allow for greater equipment cost savings, time, and convenience. For producers not presently planting on 25-cm row spacings, an equipment change would mean a great investment, but grower interest may improve because of the cost savings and convenience of planting soybean and rice on the same row spacings. (Frizzell et al., 2006). Other considerations for alternative or wider row spacings have to do with convenience or ease as the benefit of time savings associated with agronomic and cultural practices have become more valuable to producers. It is more likely for clods of soil to accrue within the coulters on a grain drill with narrower row spacing than wider row spacing. Use of a row planter rather than a drill may be of benefit to growers planting on a Sharkey clay, or other heavier soils (Hardke et al., 2018; Frizzell et al., 2006). Clods are a problem within the field because they inhibit a satisfactory seedbed. Clods can also transport weed seed and soil pests between fields, potentially introducing a harmful infestation. Maintenance of equipment is time consuming and labor intensive if these adverse scenarios are to be avoided. When planting on a 25-cm row spacing, soybean producers may see a yield benefit over wider planted rows such as 51- or 76-cm (Ashlock et al., 1996).

When narrower row spacings are implemented in soybean, improved yields may occur resulting from total dry matter accumulation and greater light interception duration (Board et al. 1990). Critical leaf area index can be reached more rapidly when narrower row spacings are used, resulting in increased radiation capture more quickly (Shibles and Weaver, 1965; Counce, 1989). Soil nitrogen (N) levels, as well as cultural practices and cultivar grown, are all accredited to rice morphological habits such as tillering (Chandler, 1969; Jones and Snyder, 1987), meaning testing and subsequent management may affect tillering and the crop canopy architecture. Yield results may not be consistent when experiments are conducted on varying soils textures, due to contrasting soil N availability. In studies where row spacing differences are drastic, the high amounts of N taken up are a result of row spacing changes. Yield losses may also be observed as a result of increased lodging due to added biomass being produced (Counce, 1989). In areas where soil N is lower, narrower row spacing is preferable rather than in areas where soil N is higher (Jones and Snyder, 1987; Tanaka et al., 1964). In an excess N scenario, row spacing should be widened to spread plants out to avoid lodging. It has also been shown that when soil fertility is sub-optimal, grain yield, yield components, tillering, and plant nutrition will not be impacted by a potassium (K) application, but a phosphorus (P) application may affect those yield components and rice grain yield. Conversely, in high fertility situations the rice grain yield and those yield components associated responded to a K application, but not a P application (Reis et al., 2018).

Row spacing and other cultural practices also influence pest management strategies in rice, as weed pressure and disease incidence can change based on rice plant density and, in some instances, row spacing cultural practices have been implemented to manage diseases in crops. When solar radiation levels are lower (Tanaka et al., 1964), such as during times when rainfall is substantial, wider row spacings are optimum (Jones and Snyder, 1987; Tanaka et al., 1964). When there is a reasonable expectation that disease will be problematic in a field, a widened crop spacing may be implemented as a prophylactic cultural practice (Howard, 1996). Plants farther apart may help in reducing disease spread. A favorable environment, a virulent pathogen, and a susceptible cultivar are all necessary at the same time for a plant disease to be present. If all three factors are not existent, then the disease will not be encountered (Wamishe et al., 2018).

It has become increasingly necessary to minimize selection for herbicide resistance through integration of cultural practices into current rice weed control programs (Norsworthy et al., 2012), especially in leu of wide spread resistance that already exists in Arkansas rice fields. Scientists in Arkansas first confirmed Group 7 photosystem II resistance in barnyardgrass (*Echinochloa crus-galli*) in 1990. Group 4 synthetic auxin resistance was later confirmed in 1999. Red rice (*Oryza sativa* var. *sylvatica*), rice flatsedge (*Cyperus iria*), smallflower umbrella sedge (*Cyperus difformis*), junglerice (*Echinochloa colona*), and yellow nutsedge (*Cyperus esculentus*) have all been confirmed resistant to Group 2 acetolactate synthase inhibitors, in 2002, 2010, 2010, and 2013, respectively (Heap, 2021). Barnyardgrass populations were also confirmed resistant to Group 13 1-deoxy-D-xyulose 5-phosphate synthetase inhibitors (Heap, 2021). Cultural practices that would favor the competitiveness of the crop over that of these resistant weeds would be beneficial to rice growers.

Through a rice producer survey in Arkansas and Mississippi, it was revealed that few growers were utilizing cultural practices likely to aid in the reduction of weed pressure (Norsworthy et al., 2013). Work has shown that weed emergence and growth are suppressed when soybean row spacings are narrowed from 76 cm to 38 cm, resulting in accelerated crop canopy formation (Teasdale, 1995). In a direct-seeded rice system, while the row spacings are much narrower, the theory remains the same that a reduced row spacing may result in decreased weed pressure as a result of earlier crop canopy formation.

During the life of the crop, stand establishment influences are necessary to understand in order to make management decisions that result in the highest possible yield. Factors that go into stand establishment need to be well understood because the management decisions that follow will ultimately determine yield. In turfgrasses, it is crucial to make appropriate planting decisions, as the impacts of poor and late stand establishment may remain for the lifetime of the plant (Richardson et al., 2001). In rice, stand uniformity is crucial when density is unsatisfactory. At a lower-than-recommended density, the plant will have adequate space and nutrients which should lead to increased tillering to make up for the lack of density. With cultivar advancements in recent years, it became necessary to reevaluate row spacing recommendations and with planting equipment improvements it will again become essential to determine appropriate row spacing. The objective of this research was to determine the impact of rice row spacing and seeding rate on stand density, grain yield, and milling yield of a variety and a hybrid. The hypothesis of this study was that an 8-cm row spacing at lower seeding rates would produce higher grain yields when compared to wider row spacings at lower seeding rates.

Materials and Methods

Field experiments were conducted in 2019 and 2020 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, AR on a DeWitt silt loam (Fine, smectitic, thermic Typic Albaqualfs) and at the Northeast Research and Extension Center (NEREC) near Keiser, AR on a Sharkey clay (very-fine, smectitic thermic Chromic Epiaquerts). A two-factor factorial randomized complete block was used with the first factor being row spacing and the second factor being seeding rate with the treatments being replicated four times. Two rice cultivars were included in this study, a pureline variety (Diamond), and a hybrid cultivar (RiceTec XP753, RiceTec Inc., Alvin, TX). These cultivars perform best under drastically different seeding rates(Hardke et al., 2018) and plant populations and therefore cultivars will not be compared within this study. For Diamond, the seeding rates evaluated were 108, 215, 323, 431, and 538 seeds m^{-2} for 8- and 19-cm row spacings and 108, 215, and 323 seeds m^{-2} for the 38-cm row spacing. For XP753, row spacings were 8-, 19-, and 38-cm wide in combination with 43, 75, 108, 140, and 172 seeds m^{-2}. Plots were 5 m in length and 1.5 m wide and were planted using an 8-row Almaco© (Almaco, Nevada, IA) drill on 19 cm spacing. Seed tubes or planting alignment were manipulated to allow for planting of the different row spacings while avoiding manipulation of individual drill row units. For achieve 8 cm row spacing, one normal pass on 19 cm spacing was planted and then a second pass was made through the same plot area shifted to plant between the rows of the first pass to create an 8 cm row spacing. The 19 cm row spacing was planted normally and modifications were not necessary. To achieve the 38 cm row spacing, seed tubes were manipulated to only allow planting from every other row unit. Stand count was determined after emergence by counting the number of seedlings that emerged in 1 row-m of rice on 2 separate rows. At the RREC and NEREC locations, when the rice reached the V5 growth stage, a single preflood N application was made at 146 kg N ha^{-1} and 180 kg N ha^{-1}, respectively. The composition of N applications consisted of urea (460 g N kg^{-1}) treated with the urease inhibitor n-butyl-thiophosphoric triamide (NBPT). All cultural practices, including fertilizer applications, were consistent with current University of Arkansas System Division of Agriculture recommendations (Roberts et al., 2018). The center rows of each plot were harvested (eight rows for 8-cm spacing, four rows for 19-cm spacing, two rows for 25-cm spacing, and two rows for 38-cm spacing) using a Wintersteiger Classic plot combine (Wintersteiger, Ried im Innkreis, Austria) when the plants reached maturity and the grain weight and moisture content were determined. The grain yield of the rice was expressed on a kg ha^{-1} (kilograms per hectare) basis, with moisture adjusted to 120 g H_20 kg^{-1}. To determine milling yield, expressed as percent head rice (%HR, whole kernels, head rice yield) and percent total white rice (%TR, total rice yield), a 100g sample was milled from each plot and a PAZ-1 laboratory rice mill (Zaccaria USA, Anna, TX) was used.

Statistical Analysis

Due to physical equipment constraints, the cultivars in this study were analyzed using different statistical models. At the time of planting, it was determined that the grain drill being used could not hold the two highest Diamond seeding rates, 431 and 538 seeds m^{-2}, respectively, for the 38-cm row spacing. This resulted in only the 108, 215, and 323 seeds m^{-2} rates being planted at the 38-cm row spacing, which led to an unbalanced design. Therefore, Diamond and RT XP753 had an uneven number of seeding rates and could not be analyzed using the same model. All data in this experiment were analyzed using the PROC GLIMMIX procedure and analysis of variance statistics with SAS version 9.4 (SAS Institute Inc., Cary, NC). For the hybrid XP753, the row spacings and seeding rates were considered fixed effects in the model and site year was considered a random effect with four levels. The means for data were separated using Fisher's protected least significant difference test at the 5% level of significance. For the pureline Diamond, seeding rate nested within row spacing was considered an effect and seeding rate was also considered as a fixed effect in the model. Site year was considered a random effect with four levels. All means were separated using Fisher's protected least significant difference test at the 5% level of significance.

Results

Diamond Stand Density

Seeding rate had an effect on stand density in Diamond (Table 3.1). The highest seeding rate at 538 seeds m^{-2} resulted in the highest stand density and subsequently decreased with each lower seeding rate (Table 3.2). The recommended stand density for pureline varieties range from

108-215 plants m^{-2} (Hardke et al., 2018), therefore the 215 and 323 seeds m^{-2} seeding rates would fall within the currently recommended stand density range.

Diamond Grain Yield

Seeding rate nested within row spacing as well as seeding rate both had an effect on rice grain yield in Diamond (Table 3.1). The 8 and 19 cm row spacings at the rates of 215-538 seeds m^{-2} resulted in greater rice grain yields than the 38 cm row spacing at all seeding rates (Table 3.3). These data show that in Diamond currently recommended row spacings and seeding rates continue to achieve acceptable yields.

Diamond Milling Yield

There was an effect of seeding rate nested within row spacing as well as seeding rate main effect on head rice yield in Diamond (Table 3.1). The 38 cm row spacing planted at 323 seeds m^{-2} resulted in greater head rice yield than all other row spacing and seeding rate combinations, except the 8 cm row spacing planted at 108 seeds m^{-2} (Table 3.3). For the 8 and 19 cm row spacings, the recommended seeding rates for Diamond did not result in different percent head rice yields (Table 3.3). In the Diamond seeding rate main effect, the 108 seeds m^{-2} rate did not result in greater head rice yield than the 215 and 323 seeds m^{-2} rates, but was higher than the 431 and 538 seeds m^{-2} rates (Table 3.2). These results were consistent with Hardke et al., (2017) which showed that percent head rice decreased as seeding rate increased. While determining the treatment effects on milling yield was a component of this study, further evaluation is necessary to extrapolate the impact that row spacing and seeding rate may have on rice milling yield.

XP753 Stand Density

For stand density in XP753, there were no row spacing by seeding rate interactions and only treatment main effects were observed (Table 3.4). Averaged across all seeding rates, as row spacing increased (Table 3.5). Averaged across row spacings stand density increased as seeding rate increased, with 172 seeds m^{-2} resulting in the highest stand density (Table 3.6) the effect XP753 seeding rates had on stand density, with the 172 seeds m^{-2} rate resulting in the highest stand density and subsequently lower stand densities with lower seeding rates (Table 3.6). These results are typical for seeding rate studies. The 75, 108, and 140 seeds m^{-2} rates produced stand densities that fall within the recommended range of 65-108 plants per m^{-2} (Hardke et al., 2018). The seeding rates are averaged across all row spacings and with the 65-108 plants per m^{-2} recommendation, the 75, 108, and 140 seeds m^{-2} rates produced the stand densities that fall within current recommendations. The recommended stand density for hybrid rice is 65-108 plants m^{-2}, but again these row spacings are averaged across all seeding rates (Table 3.5).

XP753 Grain Yield

For rice grain yield in XP753, there were no row spacing by seeding rate interactions, only treatment main effects (Table 3.4). The rice plants on 8 cm and 19 cm row spacings yielded at least 391 kg ha^{-1} more than the rice plants on the 38 cm row spacing (Table 3.5). These results show that hybrid rice planted on currently recommended 19 cm row spacing produced optimal yield. The narrowest row spacing of 8 cm, which is less than currently recommended, produced similar yields to the 19 cm spacing. While higher rice grain yields were produced by plants in the 8 and 19 cm row spacings, plants grown in the 38 cm row spacing still produced competitive yields. When evaluating seeding rate effects on grain yield, the 172 seeds m^{-2} rate resulted in the highest grain yields compared to all other seeding rates except the 140 seeds m^{-2} rate (Table 3.6). In general, grain yield increased along with seeding rate.

XP753 Milling Yield

In XP753, while there were no effects in the total rice yield there was a significant row spacing effect on head rice yield (Table 3.4). Averaged across seeding rates, the 38 cm row spacing resulted in greater head rice yield than the 19 cm row spacing. However, head rice yields were similar for rice plants grown in the 38 cm and 8 cm row spacings.

Discussion

The University of Arkansas System Division of Agriculture currently recommends a range of row spacings (10 to 25 cm) that are acceptable to achieve optimal yield (Hardke et al., 2018). In this study, only the 19 cm row spacing was within that recommended range. The 8 cm and 38 cm row spacings were below and above the recommended range, respectively. The rationale of the studies conducted was to determine the optimal row spacing and seeding rate combinations for current cultivars in direct-seeded, delayed-flood rice. For both Diamond and XP753, there were no rice grain yield differences between the 8 cm and 19 cm row spacings. The trends observed for the seeding rate main effects for both cultivars is common in seeding rate studies (Hardke et al., 2017). Given the performance of XP753 at the 38 cm row spacing additional research is needed to determine the viability of wider row spacings for hybrid cultivars. In the future, additional hybrids and row spacings should be evaluated.

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Tables

Table 3.1 The p-values from analysis of variance for stand density, grain yield, and milling yield from 2019 and 2020 at the RREC and the NEREC for Diamond.

Source	Prob. > F			
	Stand Density	Grain Yield	Total Rice	Head Rice
Spacing (Rate)	0.1636	<.0001*	0.3756	0.0038*
Rate	<.0001*	<.0001*	0.6439	0.0262*

[a] P-values within columns denoted by asterisks indicate significance.
[b] RREC: Rice Research and Extension Center.
[c] NEREC: Northeast Research and Extension Center.

Table 3.2. Impact of Diamond seeding rate on stand density, grain yield, and head rice yield from 2019 and 2020 at the RREC and the NEREC.

Seeding Rate	Stand Density	Grain Yield	Head Rice
seeds m^{-2}	plants m^{-2}	kg ha^{-1}	% head rice
108	83 e	8018 c	61.2 a
215	151 d	8699 b	60.9 ab
323	209 c	8707 b	60.9 ab
431	275 b	8917 b	60.0 bc
538	361 a	9295 a	59.8 c

[a] Means followed by the same letter within a column are not significantly different using a Fisher's protected LSD at α=0.05.
[b] RREC: Rice Research and Extension Center.
[c] NEREC: Northeast Research and Extension Center.

Table 3.3. Diamond seeding rate within row spacing effect on grain yield and head rice yield from 2019 and 2020 at the RREC and the NEREC.

Row Spacing	Seeding Rate	Grain Yield	Head Rice
cm	seeds m^{-2}	kg ha^{-1}	% head rice
8	108	8153 b	61.4 ab
	215	8950 a	61.0 bc
	323	8959 a	60.2 bc
	431	8936 a	59.8 bc
	538	9275 a	59.7 c
19	108	8327 b	61.1 bc
	215	8953 a	60.6 bc
	323	9015 a	59.5 c
	431	8898 a	60.2 bc
	538	9314 a	59.9 bc
38	108	7592 c	61.2 bc
	215	8198 b	61.1 bc
	323	8173 b	63.0 a

[a] Means followed by the same letter within a column are not significantly different using a Fisher's protected LSD at α=0.05.
[b] RREC: Rice Research and Extension Center.
[c] NEREC: Northeast Research and Extension Center.

Table 3.4. The p-values from analysis of variance for rice stand density, grain yield, and milling yield from 2019 and 2020 at the RREC and the NEREC for XP753.

	Prob. > F			
Source	Stand Density	Grain Yield	Total Rice	Head Rice
Row Spacing	<.0001*	0.0016*	0.2327	0.0431*
Seeding Rate	<.0001*	<.0001*	0.5623	0.2918
Row Spacing × Seeding Rate	0.6300	0.5481	0.9060	0.3809

[a] P-values within columns denoted by asterisks indicate significance.
[b] RREC: Rice Research and Extension Center.
[c] NEREC: Northeast Research and Extension Center.

Table 3.5. Impact of XP753 row spacing averaged over seeding rates on stand density, grain yield, and head rice yield in 2019 and 2020 at the RREC and the NEREC.

Row Spacing	Stand Density	Grain Yield	Head Rice
cm	plants m^{-2}	kg ha^{-1}	% head rice
8	93 a	10984 a	59.0 ab
19	77 b	10982 a	58.7 b
38	66 c	10591 b	59.4 a

[a] Means followed by the same letter within a column are not significantly different using a Fisher's protected LSD at α=0.05.
[b] RREC: Rice Research and Extension Center.
[c] NEREC: Northeast Research and Extension Center.

Table 3.6. Impact of XP753 seeding rate averaged over row spacing on stand density and grain yield in 2019 and 2020 at the RREC and the NEREC.

Seeding Rate	Stand Density	Grain Yield
seeds m^{-2}	plants m^{-2}	kg ha^{-1}
43	40 e	10266 c
75	66 d	10780 b
108	84 c	10891 b
140	99 b	11083 ab
172	130 a	11324 a

[a] Means followed by the same letter within a column are not significantly different using a Fisher's protected LSD at α=0.05.
[b] RREC: Rice Research and Extension Center.
[c] NEREC: Northeast Research and Extension Center.

Figures

Figure 3.1. Rice planted in 8 cm row spacing.


Figure 3.2. Rice planted in 19 cm row spacing.

Figure 3.3. Rice planted in 38 cm row spacing.

CHAPTER FOUR: Conclusions

Midsouth producers in a direct-seeded, delayed flood system are currently challenged by equipment limitations for rice seeding. Without the current ability to precision plant seed as with other crops such as soybean or corn, efforts toward agronomic improvement must focus on modifications to existing practices. Overall, in both pureline and hybrid cultivars, the crossed planting arrangement resulted in higher rice grain yields compared to the normal practice of planting in a single direction. In order for the crossed planting practice to be of benefit, input costs such as lower seeding rates or eliminating a herbicide application would be needed, while maintaining or increasing rice grain yield to offset the costs associated with an additional trip across the field. However, this study suggests that current seeding rate recommendations remain optimal for both normal and crossed planting arrangements.

For the hybrid, in the row spacing study, the 19 and 8 cm row spacings did result in rice producing higher grain yield than in the widest row spacing. The two highest hybrid seeding rates also resulted in greater yields than the currently recommended rate, however these increases may not be economically advantageous. For the pureline variety in the row spacing study, the results indicated that again the 19 and 8 cm row spacings at multiple seeding rates resulted in higher rice grain yields than the widest row spacing. The pureline seeding rate comparisons also showed a rice grain yield increase as seeding rate increased. In order to determine optimal row spacing and seeding rate combinations, further data collection is necessary.

This research is preliminary in ultimately providing recommendations to Arkansas rice producers for improving agronomics associated with planting arrangement. Further study is needed to determine whether the agronomic improvements observed in these studies result in a positive net return for producers.

APPENDIX

Table 1. Planting dates, emergence dates, fertilization dates, flood timings, and harvest dates for cross-planting trial located at the RREC and the NEREC in 2019 and 2020.

Site Year	Planting Date	Emergence Date	Fertilization Date	Flood Timing	Harvest Date
2019 RREC	15 May	21 May	17 June	18 June	19 September
2019 NEREC	28 May	5 June	1 July	2 July	3 October
2020 RREC	11 May	18 May	18 June	19 June	2 October
2020 NEREC	1 June	9 June	6 July	8 July	7 October

[a] RREC: Rice Research and Extension Center.
[b] NEREC: Northeast Research and Extension Center.

Table 2. Planting dates, emergence dates, fertilization dates, flood timings, and harvest dates for row spacing trial located at the RREC and the NEREC in 2019 and 2020.

Site Year	Planting Date	Emergence Date	Fertilization Date	Flood Timing	Harvest Date
2019 RREC	18 May	23 May	17 June	20 June	25 September
2019 NEREC	30 April	12 May	13 June	14 June	9 September
2020 RREC	17 April	1 May	15 June	16 June	18 September
2020 NEREC	22 May	29 May	16 June	17 June	30 September

[a] RREC: Rice Research and Extension Center.
[b] NEREC: Northeast Research and Extension Center.