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Evaluation of Management Practices to Mitigate Lodging for 'CL151' Rice (Oryza Sativa L.)

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Evaluation of management practices to mitigate lodging for 'CL151' rice (*Oryza sativa* L.)

By

Jennifer Leann Corbin

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Evaluation of management practices to mitigate lodging for ‘CL151’ rice (*Oryza sativa* L.)

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'CL151' a Clearfield long-grain rice cultivar, was released in 2008, based upon excellent agronomic characteristics, including excellent yield and moderately resistant rating for lodging. Further experience has indicated it's susceptibility to lodging. Lodging can reduce harvest efficiency, yield, and cause grain quality loss. The purpose of this research was to evaluate multiple management practices such as nitrogen rates and timings, seeding rate, trinexapac-ethyl application, potassium, and fungicide application to mitigate lodging for CL151. The results of this research indicate that N rate and application timing largely influence lodging incidence and grain yield. Fungicide application decreased, but did not eliminate lodging, while potassium application did not impact lodging or grain yield. Seeding rate also has a significant impact on grain yield and lodging incidence. Trinexapac-ethyl also decreased lodging incidence, but negatively impacted grain yield which was most evident when applied at 48 g ha^{-1} and applied at PD +14d growth stage.

DEDICATION

I would like to dedicate this thesis to my father Terry James. He has a great relationship with the Lord, and has taught me the importance of that for myself as well as my family. He provided for my brother and me, and continually shows me the importance of forgiveness. Without him I would not know the value of family and hard work. You have always told me what I needed to hear instead of what I wanted to hear, and constantly reminded me that an education is something that can never be taken away. Every ounce of competitive spirit (good or bad) I have comes from you. You have taught me how to be a good parent to my boys, and made me realize there is no replacement for spending quality time with the people you love. I could go on for days with things that you have done for me but instead I will close by saying, Thank you Dad for everything, and I love you.

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CHAPTER I

INTRODUCTION

Rice (*Orzya sativa* L.) is a major source of caloric intake for much of the world's population (Smith et. al 2003). In the United States rice production generally occurs in the states of Arkansas, California, Louisiana, Mississippi, Missouri, and Texas (Street and Bollich, 2003). In 2010, approximately 123,000 hectares of rice were planted and harvested in Mississippi which made it the fourth largest rice producing state in the United States behind Arkansas, Louisiana, and California. That gave Mississippi a farm-gate production value of over $226 million in 2010 (NASS, 2012).

To produce rice economically, the growing region must have high average temperatures during the growing season, an adequate supply of water that can be applied quickly, a smooth land surface with less than one percent slope, and a soil hardpan that will lessen the amount of water loss through seepage (Street and Bollich, 2003). The alluvial floodplain of the Mississippi River known as the "Delta" in Mississippi is abundant in the natural resources required to produce rice. In Mississippi, rice is primarily produced on the silty-clay- and clay-textured soils; however, some of the coarser-textured silt loams have a clay pan 6 to 10 inches below the soil surface that allows for slow percolation. Finally, because of the deep alluvial soils, land-leveling has been practiced by producers since the 1970's to further enhance sustainable rice production.

In the United States, rice is either grown in water-seeded or dry-seeded planting systems (Street and Bollich, 2003). In Mississippi, the dry seeding method is most commonly used. In a dry-seeded system, the rice seed are drilled into a smooth seedbed that has minimal weeds to a depth of approximately 3.5 cm or less. Rice emergence, depending on soil temperature and moisture, usually occurs within seven to ten days after planting. Once the plant has reached the five-to six-leaf growth stage, (approximately four weeks) a shallow permanent flood is established (Street and Bollich, 2003). Rice cultivation remains in an anaerobic environment until approximately two to three weeks prior to harvest. It is then drained at maturity to allow growers to harvest in dry field conditions.

Nutrient uptake in rice is similar to upland row crops such as corn (*Zea mays L.*) and wheat (*Triticum aestivum L.*). However, the flooded environment in which rice is grown impacts nutrient behavior and availability in the soil. This aspect dictates the way fertilizers are applied in order to maximize plant uptake and growth (Norman et al., 2003). Nitrogen (N) is absorbed by rice in two different chemical forms, ammonium (NH_4^+) and nitrate (NO_3^-). Ammonium moves through the soil solution mostly by diffusion; whereas, nitrates move by both mass flow and diffusion. The lack of oxygen in the flooded soil results in anaerobic conditions that cause NH_4^+ to be stable and accumulate in the soil and NO_3^- to be unstable in the soil because of possible loss due to leaching. Rice primarily utilizes NH_4^+ in a flooded soil environment.

Potassium availability to rice is increased after flooding due to exchangeable K^+ being displaced from the soil exchange complex into the soil solution by NH_4^+ that was applied earlier in the season (Norman et al., 2003). Potassium concentration is initially increased after flooding and is believed to remain relatively constant under flooded conditions (Norman et al., 2003).

'CL151' (Reg. No. CV-133, PI 654463), a Clearfield® (BASF, Ludwigshafen, Germany) long-grain rice cultivar, was developed by the LSU AgCenter at the Rice Research Station in Crowley, LA. It was approved for commercial release in 2008. The release of this cultivar was based upon superior agronomic characteristics such as herbicide resistance, high yield potential, good milling quality, and improved disease resistance (Blanche et al., 2011). CL151 is susceptible to sheath blight (*Rhizoctonia solani L.*), a fungal disease that spreads to the culm and can cause the tillers to lodge (Blanche et al., 2011). CL151 has a semi-dwarf growth habit, and Blanche et al. (2011) originally released it as a cultivar that was rated as moderately resistant to lodging. However, further research has demonstrated it to be very susceptible to lodging (Anonymous, 2012). Though lodging is a negative trait for rice, CL151 has remained a popular cultivar due to the yield potential relative to comparable cultivars. In Mississippi, CL151 provided a 20% greater yield advantage compared to CL131 (Kanter et al., 2011), and accounted for approximately 10% of the planted hectarage in Mississippi during 2012 and 2013 (Walker et al., 2013).

Lodging is described as the permanent displacement of stems from the vertical angle, and leads to the crop having a permanent lean or lying horizontally on the ground. Stem lodging, which results from the buckling from any part of the stem, occurs most often in CL151 (Berry et al., 2006). Lodging creates many problems for harvest, including decreased harvest efficiency, reduced grain quality, and the potential for reduced yield (Salassi et al., 2013). Agronomic factors that are believed to influence lodging are N supply and timing, potassium (K) nutrition, fungicide application, and seeding rate (Bhiah et at., 2010). Bhiah et al. (2010) reported that application of K significantly increased tiller number, plant height, and stem diameter. In those studies, lodging that occurred, was due mostly to poor root growth in the absence of K.

Nitrogen is the nutrient that is applied the most frequently and in the greatest quantity in rice production. However, there are other nutrients such as K which are also important to the rice plant (Norman et al., 2003). Potassium deficiency has not been a common problem in rice in Mississippi due to relatively high levels of native K. Potassium is absorbed by rice in the K^+ ion form; the concentration in rice tissue is greatest during the seedling stage and decreases as the plant accumulates dry matter (Sims and Place 1968; Norman et al., 2003). Approximately one-half of the total K present at physiological maturity is absorbed by panicle differentiation, therefore a large percentage of K is absorbed during reproductive growth. Accumulation of K peaks around 50% heading and then slowly declines (Norman et al., 2003).

Potassium nutrition is vital to minimize susceptibility to plant diseases such as brown spot (*Bipolariz oryzae L.*) and stem rot (*Sclerotium orzyae L.*) (Huber and Arny, 1985; Slaton et al., 1995; Maschmann et al., 2010). Stem rot is concerning because it infects the leaf sheath and the culms of the rice, and can cause a reduction in straw strength which increases lodging incidence. Stem rot can reduce yield by as much as 75% (Webster and Gunnell, 1992; Maschmann et al., 2010). Research has shown that appropriate K fertilization can have a dramatic impact on the occurrence of stem rot (Cralley, 1938; Adair and Cralley, 1950; Jain 1976; Jayaraj et al., 1991; Maschmann et al., 2010). Few chemical or biological control methods are available to reduce the incidence of stem rot. Quadris® [Azoxystrobin {methyl (E)$^{-2}$-[2[6-(2-cyanophenoxy) pyrimidin-4yloxy] phenyl]-3- methooxyacrylate}] (Syngenta Corp. Greensboro, NC) does not completely control stem rot, but may suppress its development when applied to control sheath blight (Maschmann et al., 2010).

Not only is K an essential element in growing rice, but it has shown to reduce lodging in crops such as wheat and corn. Studies conducted by Liebhardt et al., (1976), suggested that KCl applied to corn reduced lodging. They attributed decreased lodging to lower disease incidence aided by K application (Liebhardt et al., 1976). Similarly, Usherwood et al., (1975), had findings of plant lodging due to stalk deterioration and disease infestation in corn and wheat. An application of 134 kg K_2O ha^{-1} resulted in increased yields and decreased lodging incidence. Another study conducted by Bhiah et al., (2010), evaluated K application on lodging and growth of two semi-dwarf rice varieties under high N input conditions. Nitrogen application promoted vegetative growth and plant height; and regular applications of N without supplemental additions of K increased lodging incidence. When a K deficiency was observed, stem strength and diameter were reduced as well as a reduction in the number of tillers and plant height. This experiment showed that the application of K can reduce the occurrence of lodging in the presence of high N supply. In the variety, 'Amber 13', a 32% increase in stem thickness and a 30% increase in upper stem strength occurred when K was applied (Bhiah et al., 2010).

Trinexapac-ethyl [4-(cylopropyl-alpha-hydroxymethylene)-3,5-dioxo-cyclohexanecarboxylic acid ethylester] (TE), is a gibberillic acid (GA) biosynthesis inhibitor that stops production of GA_{19} to GA_{20} in the GA pathway. Palisade® EC

(Syngenta Corp. Greensboro, NC), a foliar applied plant growth regulator (PGR) manufactured by Syngenta Crop Protection Inc. contains TE as the active ingredient and is currently labeled for use in wheat, barley (*Hordeum vulgare* L.), and sugarcane (*Saccharum officinarum* L.). Its primary function is to help mitigate lodging by shortening the internodes and strengthening the stems as they elongate. Palisade® EC has demonstrated effectiveness in its ability to shorten plant height and increase straw strength, while also maintaining yield and reducing lodging (Zagonel et al., 2002; Nolte, 2007; Penckowski et al., 2009; Dai et al., 2011). Zagonel et al. (2002) and Nolte (2007) reported an increase in stem diameter and straw strength following a TE treatment in common wheat and durum wheat (*Triticum durum* Desf.). Field research conducted by Dai et al., (2011), treated wheat with two TE rates (119 g a.i. ha^{-1} and 240 g a.i. ha^{-1}) and timings (Zadoks growth stage 30 and 37) and then examined the plants for agronomic responses and lodging. In general, their findings were that all application rates and timings were effective in decreasing plant height, improving straw strength, and reducing the amount of lodging when compared to the untreated control. An application of TE at 119 g ha^{-1} during the latest growth stage and 240 g ha^{-1} at the earliest growth stage promoted lodging resistance while maintaining grain yield. Trinexapac-ethyl has also been effective in crops such as perennial rye grass (*Lolium perenne* L.). Silberstein et al. (2001), reported seed yield increased with increasing rates of TE up to the highest rate of 600 g ha^{-1}. Those plots averaged 25% more seed yield than untreated plots and lodging was also effectively controlled compared to the untreated plots. It was also evident that applications occurring at later growth stages of rye grass, negatively impacted yield.

Seeding rate is another aspect of rice production that can have an impact on yields and lead to increased incidence of lodging. Studies have shown that excessive plant population densities can cause increased plant height, weaker culms, and increased potential for lodging and disease (Dofing and Knight, 1994, Bond et al., 2008). Counce (1987) reported that ideal plant populations for non semi-dwarf rice grown in a drill-seeded environment to be 130 to 172 plants per m^{-2}. There were no significant yield losses compared to higher plant populations (Counce, 1987, Bond et al., 2008).

Nitrogen rate and seeding rate should be coupled in a rice production system. Low amounts of N can reduce grain yields, while excessive amounts of N can cause adverse agronomic effects such as lodging and increased disease pressure (Harrell et al., 2010). Seeding rates of 162 m^{-2}, 323 m^{-2}, and 646 m^{-2} were used. Rough rice yield reached a plateau at 323 m^{-2}(Bond et al., 2008). It was also shown that when N rate was increased from 67 to 134 kg ha^{-1} rice yield increased, but did not continue to increase with increasing amounts of N (Bond et al., 2008). Harrell et al. (2010) conducted a similar study using two different rice cultivars. Their findings with seed rate were in agreement with that of Bond et al. (2008) for one cultivar; however, with the second cultivar grain yield increased with increasing seed rate. The N rate fertilization results were in agreement with that of Bond et al. (2008) (Harrell et al., 2010).

‘CL151’ is a high yielding cultivar that is very susceptible to lodging. Growers can benefit from management practices that decrease lodging. Furthermore, if tools or practices are developed that reduce or eliminate lodging, cultivars with high yield potential can be considered for release rather that discarded for this negative characteristic. Therefore, the following studies are proposed: Objective 1, evaluate multiple seeding rates in combination with multiple N management strategies as a management practice to minimize lodging; Objective 2, assess the effects of multiple TE rates and timings in combination with N timings as a management practice to minimize lodging; and Objective 3, using various combinations of K rates and application timings and K rates and fungicide timings influence as a management practice to minimize lodging for CL151.

Literature Cited

Adair, C.R., and E.M., Cralley. 1950. 1949 rice yield and disease control tests. P. 9^{-2}0. Arkansas Agric. Exp. Stn., Fayetteville.

Anonymous, 2012. Horizon Ag. www.horizonseed.com/clearfield-varieties. Date verified July 2, 2012

Berry, P.M., M. Sterling, and S.J. Mooney. 2006. Development of a model of lodging for barley. J. Agronomy & Crop science 192:151^{-1}58

Bhiah, K.M., C. Guppy, P. Lockwood, and R. Jessop. 2010. Effect of potassium on rice lodging under high nitrogen nutrition. 19th World Congress for a Changing World. P. 136^{-1}39.

Blanche, S.B., X. Sha, D.L. Harrell, D.E. Groth, K.F. Bearb, L.M. White, and S.D. Linscombe. 2011. Registration of ‘CL151’ rice. Journal of Plant Registrations, Vol. 5, No. 2, May 2011 p.177^{-1}80

Bond, J.A., T.W. Walker, B.V. Ottis, and D.L. Harrell. 2008. Rice seeding and nitrogen rate effects on yield and yield components of two rice cultivars. Agron. J. 100:393-397.

Buehring, N. 2008. Mississippi rice growers’ guide. P. 4. Mississippi State Extension publication 2255.

Counce, P.A. 1987 Asymptotic and parabolic yield and linear nutrient content responses to rice population density. Agron. J. 79:864-869.

Cralley, E.M. 1938. Effects of fertilizer on stem rot of rice. Bull. 383. Arkansas Agric. Exp. Stn., Fayetteville.

Dai., J. and J.J. Wiersama. 2011. Agronomic responses and lodging of three spring wheat cultivars to trinexipac-ethyl. Online. Crop Management doi:10.1094/CM^{-2}011-0517-01-RS.

Dofing, S.M., and C.W. Knight. 1994. Yield component compensation in uniculm barley lines. Agron. J. 86:273^{-2}76.

Harrell, D.L., and S.B. Blanche. 2010. Tillage, seeding, and nitrogen rate effects on rice density, yield and yield components of two rice cultivars. Agron. J. 102:592^{-2}97.

Huber, D.M., and D.C. Arny. 1985. Interactions of potassium with plant disease. P. 467-479. *In* R.D. Munson (ed.) Potassium in Agriculture. ASA, CSSA, and SSSA, Madison, WI.

Jain, S.S. 1976. Studies on the effects of nitrogen, phosphorous, and potassium on stem rot of rice. ORZYA 13:55-61.

Jayaraj, J., K. Ramanujam, and R. Ramabadran. 1991. Effect of potash nutrition on the stem rot incidence and yields of rice. J. Pot. Res. 7:62-66

Kanter, D.G., T.W. Walker, N.W. Buehring, W. L. Soloman, L.S. Lanford, S. Shaifer, P. Fitts, and J.L. Corbin. 2011. Mississippi rice variety trials. Mississippi Agriculture & Forestry Experiment Station publication.

Liebhardt, W.C. and R.D. Munson. 1976. Effect of chloride and potassium on corn lodging. Agron. J. 68:425-426.

Maschmann, E.T., N.A. Slaton, R.D. Cartwright, and R.J. Norman. 2010. Rate and timing of potassium fertilization and fungicide influence rice yield and stem rot. Agron. J. 102:163^{-1}70.

National Agricultural Statistics Service (NASS). 2012. Published estimates database. National Agricultural Statistics Service website [Online]. Available at http://www.nass.usda.gov/QuickStats/PullData_US.jsp (verified 6 Jan. 2012).

Nolte. K. 2007. The PGR trinexipac-ethyl reduces lodging in desert durum wheat. HortScience 42:865-866.

Norman, R.J., C.E. Wilson, Jr., N.A. Slaton. 2003. Soil fertilization and mineral nutrition in U.S. mechanized rice culture. P.331-411. *In* C. Wayne smith and Robert H. Dilday (ed.) Rice: Origin, History, Technology, and Production. John Wiley & Sons, Hoboken, New Jersey.

Pencowski, L.H., J. Zagonel, and E.C. Fernandes. 2009. Nitrogen and growth reducer in high yield wheat. Acta Sci. Agron. 31:473-479

Salassi, M.E., M.A. Deliberto, S.D. Linscombe, C.E. Wilson, Jr., T.W. Walker, G.N. McCauley, and D.C. Blouin. 2013. Impact of harvest lodging on rough rice milling yield and market price. Agron. J. 105:1860^{-1}867.

Sims, J.L. and G.A. Place. 1968. Growth and nutrient uptake of rice at different growth stages and nutrient levels. Agron. J. 60:692-696.

Silberstein, T.B., W.C. Young III, T.G. Chastain, and C.J. Garbacik. 2001. Response of cool season grasses to foliar applications of palisade (trinexipac-ethyl) plant growth regulator.

Slaton, N.A., R.D. Cartwright, and C.E. Wilson, Jr. 1995. Potassium deficiency and plant diseases observed in rice fields. Better Crops 79:12^{-1}4.

Smith, C.W., R.H. Dilday. 2003. Preface. P. vii-viii. *In* C. Wayne smith and Robert H. Dilday (ed.) Rice: Origin, History, Technology, and Production. John Wiley & Sons, Hoboken, New Jersey.

Street, J. E., and P.K. Bollich (2003). Rice production. P. 271^{-2}96. *In* C. Wayne Smith and Robert H. Dilday (ed.) Rice: Origin, History, Technology, and Production. John Wiley & Sons, Hoboken, New Jersey.

Usherwood, N.R. 1975. Reduce lodging with potassium. Better Crops Plant Food 46:6^{-1}1.

Walker, T.W., R.L. Atwill, J.L. Corbin, P.W. Fitts, L.S. Lanford, and S.D. Shaifer. 2013. Mississippi rice variety trials. Miss. Agric. and For. Exp. Stn. Information Bulletin No. 481. Mississippi State, MS.

Webster, R.K., and P.S. Gunnell. 1992. Compendium of rice diseases. APS Press, St. Paul, MN.

Zagonel, J., W.S. Venancio, and R.P. Kunz. 2002. Effect of growth regulator on wheat crop under different nitrogen rates and plant densities. Planta Daninha 20:471-476.

CHAPTER II

EVALUATION OF SEED RATE AND NITROGEN APPLICATION STRATEGIES TO MINIMIZE LODGING IN ‘CL151’

Abstract

‘CL151’ a Clearfield® (BASF, Ludwigshafen, Germany) long-grain rice cultivar, developed by LSU AgCenter Rice Research Station (RRS) in Crowley, LA, was released in 2008. Its release was based upon excellent agronomic characteristics, including a moderately resistant rating for lodging. Further experience has indicated it’s susceptibility to lodging. Lodging can reduce harvest efficiency, yield, and cause grain quality loss. CL151 continues to account for a considerable portion of the market share because of its red rice control and excellent yield potential. The objective of this study was to evaluate the impact of seeding rate in combination with multiple nitrogen (N) fertilizer schemes to minimize lodging for CL151. Field experiments were conducted in 2010 and 2012 at the Delta Research and Extension Center (DREC), in Stoneville, MS, and the RRS in 2010. Replicated treatments consisted of a factorial combination of three seed rates (161, 323, and 483 seeds m^{-2}) and ten combinations of N rates and splits, termed strategies, for a total of 30 treatments. Nitrogen strategies consisted of 101 to 252 kg N ha^{-1} applied pre-flood (PF), 0 or 50 kg N ha^{-1} at panicle differentiation (PD), and 0 or 50 kg N ha^{-1} at heading (HD). Grain yields for CL151 were greatest when 323 seeds m^{-2} were planted and by applying a total PF N rate of 201 or 252 kg N ha^{-1}. However,

323 seeds m^{-2} in combination with PF N rates of 201 or 252 kg N ha^{-1} increased lodging intensity and percentage. Results indicated that 95% of total yield can be achieved by applying split applications of N (151 kg N ha^{-1} PF followed by 50 kg N ha^{-1} PD) and using a seeding rate of 323 or 483 seeds m^{-2}. Applying adequate rates of N in combination with a seed rate of 323 seeds m^{-2} significantly decreased lodging while maintaining high yield.

Introduction

A uniform plant stand is critical in attaining high grain yields in rice. Key elements in the producer's ability to establish optimum plant density include: conditions of the seedbed, seed germination, seedling vigor, cultivar, and soil temperature, all of which are crucial in determining the final plant population (Bond et al., 2005). Drill seeded rice is placed in discrete rows and plant competition varies greatly when seeding rate is changed (Jones and Snyder, 1987). Tiller production is directly affected by the density of the plant population (Schnier et al., 1990; Counce et al., 1992; Bond et. al., 2008); however, it is possible for some cultivars to compensate for plant densities that are initially lower by an increase in the amount of tillering (Counce et al., 1992; Gravois et al., 1996). The recommended seeding rates for Louisiana rice production range from 215 to 323 seeds m^{-2}. This allows for obtaining a density of 108 to 161 seedlings m^{-2} (Saichuck et al., 2008; Harrell, et al., 2010). Research conducted previously has shown that lower seeding rates in rice do not always negatively impact grain yield (Jones and Snyder, 1987; Gravois and Helms, 1992; Ottis and Talbert, 2005; Harrell et al., 2010). However, research conducted with more recent rice cultivars suggests that low seeding rates can have a negative impact on rice grain yields (Bond et al., 2005, 2008). When plant density becomes excessive it can lead to greater plant heights, weaker culms, increased disease potential and lodging (Dofing and Knight, 1994; Bond et al., 2008; Harrell et el., 2010).

In the southern United States, rice is produced in a dry-seeded, delayed-flood cultural system. Historically, rice has produced optimum grain yields when urea is applied in split applications (Wells and Johnston, 1970; Reddy and Patrick, 1976; Wells and Turner, 1984; Patrick et al., 1985; Brandon and Wells, 1986; Wescott et al., 1986; Wilson, et al., 1998), but more recent research indicates that rice uses N more efficiently when applied in a single preflood (PF) application (Bollich et al. 1994, Norman et al., 1999, and Bond et al., 2008). Studies have shown that rice cultivars grown in the United States show a grain yield response when relatively high N rates are used. In order to produce an optimum grain yield, proper N rate and timing are imperative. In the southern United States, N fertilizer efficiency has been greatest when at least half of the total N is applied PF followed by the remaining N applied between internode elongation (IE) to 10 days after IE (Brandon et al., 1982; Mengel and Wilson, 1988; Wilson et al., 1989; Wilson et al., 1998; Walker et al., 2006). Nitrogen application studies conducted outside the United States have reported that N applied during later stages of reproductive growth have also had an impact on rough rice yields (Perez et al., 1996; Wopereis-Pura et al., 2002; Walker et al., 2006). Nitrogen rate recommendations are often based upon cultivar and soil type. Applying inadequate levels of N can cause a severe reduction in grain yield. However, applying N at excessive rates can cause unwanted agronomic effects such as, greater plant height and increased disease pressure that can result in potential grain yield loss due to lodging (Gravois and Helms, 1996; Bond et al., 2008; Harrell et al., 2010). Research conducted by Wells and Johnston (1970) suggested that mid-season N applications could be timed to maximize grain yield and minimize lodging.

'CL151' (Reg. No. CV-133, PI 654463), a Clearfield® (BASF, Ludwigshafen, Germany) long-grain rice cultivar, was developed by the LSU AgCenter at the Rice Research Station (RRS) in Crowley, LA, and approved for release in 2008. The release of this cultivar was based upon superior agronomic characteristics such as herbicide resistance, high yield potential, good milling quality, and improved disease resistance (Blanche et al., 2011). CL151 has a semi-dwarf growth habit, and was originally released as a cultivar rated moderately resistant to lodging. Research and practical experience since its release indicated it to be very susceptible to lodging (Anonymous, 2012). Though lodging is a negative trait for rice, CL151 has remained a popular cultivar due to the yield potential relative to comparable cultivars. For example, in Mississippi, CL151 averaged 11,391 kg ha^{-1} during 2010 to 2011 compared to 9,475 kg ha^{-1} for 'CL131' (patent number US 7 786 360 B2), a cultivar that has exceptional tolerance to lodging (Kanter et al., 2011). Tools and practices developed to minimize lodging would be beneficial to aid cultivars with high yield potential to be considered for release instead of discarded because of this negative characteristic.

The objective of this research was to evaluate multiple seeding rates in combination with multiple N fertilizer schemes as a management practice to minimize lodging for the rice cultivar 'CL151' while maintaining high yield potential. We hypothesize that a high seed rate in combination with high N fertilizer application will lead to adverse agronomic effects and potential lodging, but that a reduced seed rate in combination with an adequate N management practice will optimize yields and minimize lodging.

Materials and Methods

Site Description and Cultural Practices

Field studies were conducted at three sites over a two year period. In 2010 and 2012 field experiments were conducted on a Tunica clay (clayey over loamy, mixed, superactive, nonacid, thermic, Vertic Epiaquerts) soil at the Delta Research and Extension Center (DREC), Stoneville, MS. In 2010 the study was conducted on a Crowley silt loam (fine, smectitic, thermic Typic Albaqualfs) soil at RRS. Soil textures were identified using the USDA-NRCS soil survey information (USDA-NRCS, 2013). CL151 was drill seeded using a Great Plains drill (Great Plains Mfg., Inc., Salina, KS) and produced in a delayed-flood culture. Seeding occurred on 14 March and 28 April 2010 which are in the optimum planting windows for RRS and DREC, respectively. Seeding occurred on 9 April 2012 at DREC. A permanent flood was established at the 5- to 6- leaf growth stage of rice and maintained until approximately two weeks prior to harvest. The experimental units (plots) consisted of eight, 4.6-m rows spaced 20-cm apart. There were four replications, and each replication was separated by a 1.6-m alley. The trials were randomized complete blocks with treatments defined by a 3 (seed rate) x 10 (N application strategies) factorial combination of treatments. Seed rates were 161, 323, and 483 seeds m^{-2}. Nitrogen application strategies were 101, 151, 201 and 252 kg N ha^{-1} applied pre-flood (PF), 101 and 151 kg N ha^{-1} applied PF followed by 50 kg N ha^{-1} applied at panicle differentiation (PD), 101 and 151 kg N ha^{-1} applied PF followed by 50 kg N ha^{-1} applied at heading (HD), and 101 and 151 kg N ha^{-1} applied PF followed by 50 kg N ha^{-1} at PD and 50 kg N ha^{-1} at HD. Pre-flood N was applied with a custom-manufactured, self-propelled fertilizer distributer equipped with a Hege 80 belt cone (Wintersteiger, Inc., Salt Lake City, UT) and zero-max (Zero-Max, Inc., Plymouth, MN) to provide accuracy and precision. The PD and HD applications of N were broadcast by hand into each plot into the flood water. Plots were managed according to University recommendations for each respective state where trials were located to minimize weed and insect pest pressure (Buehring et al. 2008 and Saichuck et al. 2008).

Data Collection

Immediately before harvest all plots were visually rated for lodging intensity on a scale of 1 to 5 (1= erect, 3= 45 degree angle, and 5= horizontal and matted to the ground) and lodging percent (percent of the plot lodged). Plots were harvested when grain moisture for the latest maturing plots was below 220 g kg^{-1} with a Wintersteiger Delta small plot combine (Wintersteiger, Inc., Salt Lake City, UT) equipped with a Harvest Master grain gauge (Juniper Systems, Inc., Logan UT). The Harvest Master system was used for measuring grain weight and moisture. Yields were standardized to 120 g kg^{-1} moisture content for analysis.

Statistical Analysis

PROC MIXED (SAS, 2008) was used to test fixed effects and interactions among fixed effects. The three site years were termed environments. Replication nested within environment was considered a random effect so that broader inferences could be obtained about managing this cultivar across the southern United States (Carmer et al., 1989). Seeding rate and N application strategies were considered fixed effects. Analysis of variance was conducted for rice grain yield, lodging percent and lodging intensity. Least square means at the $P < 0.05$ was used for mean separation.

Results and Discussion

Lodging Percent and Lodging Intensity

The percent of the plot lodged was affected by the interaction of seeding rate and N application strategy (Table 2.1). Lodging was greatest when seed rates of 323 and 483 seeds m^{-2} were used in combination with the PF application of 201 or 252 kg N ha^{-1} (Table 2.2). Within each seeding rate, lodging was greater when 252 kg N ha^{-1} was applied compared to 201 kg N ha^{-1}. Furthermore, within an N rate, lodging increased with increasing seeding rate reaching a maximum of 51% at 252 kg N ha^{-1} and 33% at 201 kg N ha^{-1}. When 161 seeds m^{-2} was drilled and N applied at 252 kg N ha^{-1} percent of the plot lodged was 20% and 25% less than when compared to that same N application and seeding 323 and 483 seeds m^{-2}, respectively (Table 2.2). An 18% and 30% reduction in the percent of the plot lodged was observed with seeding rates of 323 and 161 seeds m^{-2} and 201 kg N ha^{-1} was applied PF compared to that same N scheme seeded at 483 seeds m^{-2} (Table 2.2). Similar to percent of the plot lodged, lodging intensity was also affected by the seeding rate and N application strategy interaction (Table 2.1). Intensity was greatest when 323 and 483 seeds m^{-2} were planted and the N was applied at 252 kg N ha^{-1} 100% PF (Table 2.3). With seed rates of 161 or 323 seeds m^{-2} and, when total N was decreased or applied in split applications, the intensity of lodging was much less than when the combination of 483 seeds m^{-2} and 252 kg N ha^{-1} was used. Similarly, Bond et al. (2005) suggested that lodging increased with increasing seed rate. Wells and Johnston (1970) reported that midseason N application timing was a major factor in a cultivars susceptibility to lodging, which differ from these data. The greatest incidence of lodging occurred when 323 and 483 seeds m^{-2} were seeded in combination with the greatest rates of N (201 or 252 kg ha^{-1}) applied PF.

Grain Yield

Rice grain yield was significantly affected by the main effects of seed rate and N application scheme, but not the interaction of the two main effects (Table 2.1). Pooled over N application scheme, a grain yield reduction of 4.8% was observed when 161 seeds m^{-2} were used compared to 323 or 483 seeds m^{-2} (Table 2.4). These data suggest that the greatest grain yield can be achieved when seed is planted at a rate of 323 seeds m^{-2}. These findings are in agreement with research done previously (Bond et al., 2005; Harrell et al., 2010) which advises that yield potential is greatest in most years when rice is seeded at 323 seeds m^{-2} in a drill-seeded, delayed-flood system. Seed rate results are in disagreement with previous research which suggests that seed rates of less than 323 seeds m^{-2} were sufficient and able to overcome lower plant densities by producing more tillers, which in turn allow for higher grain yields at harvest (Jones and Snyder, 1987; Gravois and Helms, 1992; Ottis and Talbert, 2005). Grain yield was also affected by N application stratey. Pooled over seed rate, yields were greatest when rates of 201 or 252 kg N ha^{-1} were applied PF. There was a 3% decrease in yield when N was applied at 151 kg N ha^{-1} PF, 50 kg ha^{-1} PD, and 50 kg ha^{-1} at HD, and a 4% decrease in yield when applied at151 kg ha^{-1} PF followed by 50 kg N ha^{-1} PD when compared to the single PF rate of 201 kg N ha^{-1} (Table 2.4). This indicates that rice yield potential is predominantly determined by PF N rate which is in agreement with more recent research (Mengel and Wilson 1988; Norman et al., 2000; Wilson et al., 1988; Slaton et al. 2003; Slaton et al., 2004; Walker et al., 2006). Grain yield for each of the 30 treatment combinations are listed in Table 2.4. Percent of the plot lodged and lodging intensity for the treatment combinations are listed in Tables 2.3 and 2.4, respectively. A review of the data on an individual treatment basis allowed for recommendations to be made for obtaining various levels of yield potential with the respective lodging potential. .

Conclusion

Maximum rice grain yields for CL151 can be achieved with a seed rate of 323 seeds m^{-2} and a total PF N rate of 201 or 252 kg ha^{-1} for the cultivar CL151. However, that seed rate in combination with PF N rates of 201 or 252 kg N ha^{-1} proved to increase the intensity and incidence of lodging. Appropriate N management in combination with a seed rate of 323 seeds m^{-2} significantly decreases lodging intensity and percent while maintaining high yield potential for CL151. Based on these findings, CL151 can obtain within 95 percent yield potential with no lodging when 161 seeds m^{-2} is planted with 201 kg N ha^{-1} applied PF, or by planting 323 seeds m^{-2} with 151 kg N ha^{-1} applied PF and a top dress application of 50 kg N ha^{-1} applied at either PD or HD.

Table 2.1 Test of fixed effects and interactions for three site years for rice grain yield, percent of the plot lodged, and lodging intensity.

	Grain Yield	% Lodging	Lodging Intensity
Source		Pr > F	
Seed Rate	<0.0001	0.0003	0.00159
Nitrogen Application†	<0.0001	<0.0001	<0.0001
Nitrogen Application*Seed Rate	NS‡	0.0001	0.0374

† Nitrogen application scheme
‡ NS, not significant at the P = 0.05 level.

Table 2.2 Percent of the plot lodged as affected by seeding rate x N application strategies at pre-flood (PF), panicle differentiation (PD), or heading (HD) pooled over seeding rate for three site years.

Nitrogen Scheme	PF	PD	HD	Plot lodged % Seed rate (seeds m^{-2})		
		kg N ha^{-1}		161	323	483
1	101	0	0	0	0	0
2	101	0	50	0	0	0
3	101	50	0	0	0	0
4	101	50	50	0	0	0
5	151	0	0	0	0	0
6	151	0	50	0	0	0
7	151	50	0	0	2	5
8	151	50	50	1	3	7
9	201	0	0	2	15	33
10	252	0	0	25	45	51
	LSD				10	

Table 2.3 Lodging intensity (1-5) as affected by an interaction of seeding rate x N application scheme {pre-flood (PF), panicle differentiation (PD), or heading (HD)} pooled over three site years.

Nitrogen Scheme	PF	PD	HD	Lodging intensity (1-5) Seed rate (seeds m^{-2})		
		kg N ha^{-1}		161	323	483
1	101	0	0	1.0	1.0	1.0
2	101	0	50	1.0	1.0	1.0
3	101	50	0	1.0	1.0	1.0
4	101	50	50	1.0	1.0	1.0
5	151	0	0	1.0	1.0	1.0
6	151	0	50	1.0	1.0	1.0
7	151	50	0	1.0	1.0	1.1
8	151	50	50	1.0	1.0	1.1
9	201	0	0	1.0	1.4	2.0
10	252	0	0	1.7	2.4	2.4
	LSD				0.4	

Table 2.4 Rice grain yield as affected by the main effects of seeding rate and nitrogen (N) management schemes {pre-flood (PF), panicle differentiation (PD), or heading (HD)}.

Nitrogen Scheme	PF	PD	HD	Seeding rate (seeds m^{-2})			Grain yield †
		kg N ha^{-1}		161	323	483	LS Means$_{\text{nitrogen scheme}}$
					kg ha^{-1}		
1	101	0	0	9287	9724	9827	9612 A§
2	101	0	50	10016	10055	10053	10041 A
3	101	50	0	9942	10535	10646	10375 B
4	101	50	50	10015	10616	10647	10426 B
5	151	0	0	10577	10949	11068	10864 C
6	151	0	50	10720	11200	11115	11011CD
7	151	50	0	10446	11246	11501	11064 CD
8	151	50	50	10761	11408	11333	11166 DE
9	201	0	0	11212	11567	11659	11479 F
10	252	0	0	11293	11772	11226	11431 EF
	LSMeans$_{\text{seed rate}}$		†	10427 b§	10907 a	10908 a	

† Average grain yield pooled over site years and seeding rate.

‡ Average grain yield pooled over site years and nitrogen management scheme.

§ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$.

Literature Cited

Anonymous, 2012. Horizon Ag. www.horizonseed.com/clearfield-varieties. Date July 2, 2012

Blanche, S.B., X. Sha, D.L. Harrell, D.E. Groth, K.F. Bearb, L.M. White, and S.D. Linscombe. 2011. Registration of 'CL151' rice. Journal of Plant Registrations, Vol. 5, No. 2, May 2011 p.177^{-1}80.

Bollich, P.K., C.W. Lindau, and R.J. Norman. 1994. Management of fertilizer nitrogen in dry-seeded, delayed-flood rice. Aust. J. Exp. Agric. 34:1007–1012.

Bond, J.A., T.W. Walker, P.K. Bollich, C.H. Koger, and P.Gerard. 2005. Seeding rates for stale seedbed rice production in the midsouthern United States. Agron. J. 97:1560^{-1}563.

Bond, J.A., T.W. Walker, B.V. Ottis, and D.L. Harrell. 2008. Rice seeding and nitrogen rate effects on yield and yield components of two rice cultivars. Agron. J. 100:393-397.

Brandon, D.M., D.B. Mengel, F.E. Wilson, Jr., and W.J. Leonards, Jr. 1982. Improving nitrogen efficiency in rice. Louisiana Agric. 26:4-6.

Brandon, D.M. and B.R.Wells. 1986. Improving nitrogen fertilizer in mechanized rice culture. P. 161^{-1}70. *In* S.K. DeDatta and W.H. Patrick, Jr. (ed.) Nitrogen economy of flooded rice soils, Martinus Nijhoff Publ. Co., Dordrect, the Netherlands.

Buehring, N. 2008. Mississippi rice growers guide. Mississippi State Extension publication 2255.

Carmer, S. G., W. E. Nyquist, and W. M. Walker. 1989. Least significant differences for combined analysis of experiments with two or three-factor treatment designs. Agron. J. 81:665–672.

Counce, P.A., B.R. Wells, and K.A. Gravaois. 1992. Yield and harvest index responses to preflood nitrogen fertilization at low rice plant populations. J. Prod. Agric. 5:492-497.

Dofing, S.M., and C.W. Knight. 1994. Yield component compensation in uniculm barley lines. Agron. J. 86:273^{-2}76.

Gravois, K.A., and R.S. Helms. 1992. Path analysis of rice yield components as affected by seeding rate. Agron. J. 84:1-4.

Gravois, K.A., and R.S. Helms. 1996. Seeding rate effects on rough rice yield, head rice, and total milled rice. Agron. J. 88:82-84.

Harrell, D.L., and S.B. Blanche. 2010. Tillage, seeding, and nitrogen rate effects on rice density, yield and yield components of two rice cultivars. Agron. J. 102:592^{-2}97.

Jones, D.B., and G.H. Snyder. 1987. Seeding rate and row spacing effects on yield and yield components of drill-seeded rice. Agron. J. 79:623-626.

Kanter, D.G., T.W. Walker, N.W. Buehring, W. L. Soloman, L.S. Lanford, S. Shaifer, P. Fitts, and J.L. Corbin. 2011. Mississippi rice variety trials, 2011. Mississippi Agriculture & Forestry Experiment Station publication.

Mengel, D.B., and F.E. Wilson. 1988. Timing of nitrogen fertilizer for rice in relation to paddy flooding. J. Prod. Agric. 1:90-92.

Norman, R.J., C.E. Wilson, Jr., N.A. Slaton, K.A.K. Moldenhauer, D.L. Boothe, S.D. Clark, and A.D. Cox. 2000a. Grain yield response of new rice cultivars. p. 267–271. *In* R.J. Norman and C.A. Beyrouty (ed.) Arkansas rice research studies 1999. Res. Ser. 476. Arkansas Agric. Exp. Stn, Fayetteville.

Norman, R.J., C.E. Wilson, Jr., N.A. Slaton. 2003. Soil fertilization and mineral nutrition in U.S. mechanized rice culture. P.331-411. *In* C. Wayne smith and Robert H. Dilday (ed.) Rice: Origin, History, Technology, and Production. John Wiley & Sons, Hoboken, New Jersey.

Ottis, B.V., and R.E. Talbert. 2005. Rice yield components as affected by cultivar and seeding rate. Agron. J. 97:1622^{-1}625.

Patrick, W.H. Jr., D.S. Mikkelson, and B.R. Wells. 1985. Plant nutrient behavior in flooded soil. P. 197^{-2}28. *In* O.P. Engelstad (ed.) Fertilizer technology and use. 3rd ed. SSSA, Madison, WI.

Perez, C.M., J.M. Alcantara, K.G. Cassman, B.O. Juliano, and S.P. Liboon. 1996. Effects of late nitrogen fertilizer application on head rice yield, protein content, and grain quality of rice. Cereal Chem. 73:556-560.

Reddy, K.R., and W.H. Patrick, Jr. 1976. Yield and nitrofen untilization by rice as affected by method and time of application of labelled nitrogen. Agron. J. 68:965-969.

Saichuck, J.K., S.B. Blanche, E. Eskew, D.L. Harrell, D.E. Groth, C. Hollier, N. Hummel, S.D. Linscombe, C. Rush, X. Sha, M. Stout, E. Webster, and L.M. White. 2008. Rice varieties and management tips 2009. Louisiana Coop. Ext. Serv., Baton Rouge.

Schnier, H.F., M. Dingkuhn, S.K. De Datta, K. Mengal, E. Wijangco, and J.E. Faronilo. 1990. Nitrogen fertilization of direct seeded vs. transplanted rice: I. Nitrogen uptake, photosynthesis, growth, and yield. Crop Sci. 30:1276^{-1}284.

Slaton, N.A., R.D. Cartwright, J. Meng, E.E. Gbur Jr., and R.J. Norman. 2003. Sheath blight severity and rice yield as affected by nitrogen fertilizer rate, application method, and fungicide. Agron. J. 95:1489^{-1}496.

Slaton, N.A., E.E. Gbur, R.D. Cartwright, R.E. DeLong, R.J. Norman, and K.R. Brye. 2004. Grain yield and kernel smut of rice as affected by preflood and midseason nitrogen fertilization in Arkansas. Agron. J. 96:91-99.

United States Department of Agriculture, National Resources Conservations Services. USDA-NRCS. 2013. Web soil survey. Available at http://websoil.survey.nrcs.usda.gov/app/WebSoilSurvey.aspx (verified 18 December 2013). USDA-NRCS, Washington, DC.

Walker, T.W. 2006. Rice grain yield response to nitrogen fertilization for newly released cultivars and hybrids. Res. Rep. 23:20. Mississippi Agric. And For. Exp. Stn., Mississippi State, MS.

Walker, T.W., S.W. Martin., and P. Gerard. 2006. Grain yield and milling quality response of two rice cultivars to top-dress nitrogen application timings. Agron. J. 98:1495^{-1}500.

Wells, B.R., and F.T. Turner. 1984. Nitrogen use in flooded rice soils. p. 349-362. *In* R.D. Hauck (ed.) Nitrogen in crop production. ASA, CSSA, and SSSA, Madison, WI.

Wells, B.R., and T.H. Johnston. 1970. Differential response of rice varieties to timing of mid-season nitrogen applications. Agron. J. 62:608-612.

Westsott, M.P., D.M. Brandon, C.W. Lindau, and W.H. Patrick, Jr. 1986. Effects of seeding method and time of fertilization on urea-nitrogen^{-1}5 recovery in rice. Agron. J. 78:474-478.

Wilson, C.E., Jr., R.J. Norman, and B.R. Wells. 1989. Seasonal uptake patterns of fertilizer nitrogen applied in split applications to rice. Soil Sci. Soc. Am. J. 53:1884^{-1}887.

Wilson, C.E., Jr., P.K. Bollich, and R.J. Norman. 1998. Nitrogen application timing effects on nitrogen efficiency or dry-seeded rice. Soil Sci. Soc. Am. J. 62:959-964.

Wopereis-Pura, M.M., M.C.S. Wopereis, J. Moreira, and H. Watanabe. 2002. Effect of late nitrogen application on rice yield, grain quality, and profitability in the Senegal River Valley. Eur. J. Agron. 17:191^{-1}98.

CHAPTER III

EVALUATION OF TRINEXAPAC-ETHYL RATES AND TIMINGS WITH NITROGEN MANAGEMENT PRACTICES TO MINIMIZE LODGING FOR ‘CL151’

Abstract

‘CL151’ a Clearfield® (BASF, Ludwigshafen, Germany) long grain rice cultivar, has become popular for rice production in the southern United States. It offers a tolerance to Newpath® and Beyond® herbicides for control of red rice, and has also shown excellent yield potential. Expansion of CL151 has been slowed because of its susceptibility to lodging, which can decrease harvest efficiency, grain quality, and yield. Trinexapac-ethyl (TE) is a foliar absorbed plant growth regulator that can inhibit shoot growth in plants. In 2012 and 2013 field studies were conducted at five different sites in the Mississippi alluvial plain to determine if foliar application of TE could be utilized as an effective practice to minimize lodging for CL151. In addition to lodging, this study also measured the potential impact of TE on plant height, milling quality, stem thickness, panicle length, and rice grain yield. Sixteen treatment combinations consisting of two nitrogen (N) application schemes [100% N applied pre-flood (PF) or 75% N applied PF followed by the remaining 25% at panicle differentiation (PD)], four TE rates (0, 12, 24, and 48 g ha^{-1}), and two TE timings [PD or 14 d after PD (PD+14)]. Averaged across similar soil types, TE effectively reduced plant height from 102 cm to 88 cm. Lodging

was reduced when TE was applied at any rate. Stem diameter was unaffected on either soil type, but panicle length was reduced on the silt loam from 18.5 cm to 17.9 cm when 48 g ha^{-1} of TE was applied on silt loam soils. There was also a reduction from 18.7 cm to 17.7 cm when TE was applied at PD+14. Grain yields were negatively impacted on both soil types. Grain yield was 13,175 kg ha^{-1} when TE was not applied and decreased 15% when 48 g ha^{-1} was applied at PD + 14 on the silt loam soil. Grain yield was greatest for the clay soils (12,163 kg per ha^{-1}) when TE was not applied and tended to decrease with increasing TE rate. Trinexapac-ethyl showed potential as a management practice to minimize lodging for CL151, however, high rates could potentially result in substantial loss in grain yield.

Introduction

Rice (*Orzya sativa* L.) is a primary source of food for more than half of the world's population. Rice cultivation within the United States occurs mainly in the southeastern region in the states of Mississippi, Arkansas, Texas, Missouri, and Louisiana (Street and Bollich, 2003). Rice has provided average gross returns of more than $2,400 ha^{-1} the last two years so it is considered to be a relatively high value crop (Salassi et. al 2013; USDA, 2013). Global markets make up a large portion of rice produced in the United States, (USDA, 2013) so it is important to maintain high grain yields per unit of land area to be competitive with world prices. Grain quality of rice is also important. Rough rice yield per hectare is a key factor in determining the market value of a crop, and many cultivars with exceptional yield potential have become available in recent years because of advances in plant breeding and crop management (Ottis et al., 2005; Moldenhaur et al., 2001).

In 2008, LSU AgCenter Rice Research Station in Crowley, LA, released 'CL151' (Reg. No. CV-133, PI 654463), a Clearfield® (BASF, Ludwigshafen, Germany) long-grain rice cultivar. This cultivar was considered to have superior agronomic characteristics such as herbicide resistance, high yield potential, good milling quality, and improved disease resistance (Blanche et al., 2011). CL151 has a semi-dwarf growth habit and when originally released was rated moderately resistant to lodging (Blanche et al. 2011). However, further research has demonstrated it to be very susceptible to lodging (Anonymous, 2012). Lodging is an undesirable trait for rice because it can slow the harvest process, cause loss of grain quality, and reduce grain yields. Even with the cultivar's susceptibility to lodging, CL151 has remained a popular cultivar due to the high yield potential relative to comparable cultivars. In Mississippi, CL151 has averaged 11,391 kg ha^{-1} over the last three years compared to 9,475 kg ha^{-1} for 'CL131' (patent number US 7 786 360 B2), a lodging resistant cultivar, and accounted for 10% of the planted hectarage in Mississippi when averaged for 2012 and 2013 (Kanter et al., 2011; Walker et al., 2013). Developing management practices to minimize lodging could potentially allow cultivars with high yield potential to be considered for release instead of discarded because of this negative characteristic.

Trinexapac-ethyl [4-(cylopropyl-alpha-hydroxymethylene)-3,5-dioxo-cyclohexanecarboxylic acid ethylester] (TE) was registered as a plant growth regulator (PGR) in 1998. It is a gibberillic acid (GA) biosynthesis inhibitor that stops production of GA_{19} to GA_{20} in the GA pathway, and is a foliar absorbed cyclohexanedione PGR that can inhibit shoot growth in plants (Unan et al., 2013). Palisade® EC, a foliar applied PGR manufactured by Syngenta Crop Protection Inc., Greensboro, NC, contains TE as the active ingredient and is currently labeled for use in wheat (*Triticum*), barley (*Hordeum vulgare*), and sugarcane (*Saccharum*). Its primary function is to help mitigate lodging by shortening the internodes and strengthening the stems as they elongate. Although not currently labeled for rice production, TE has shown to be effective in crops such as winter and spring wheat, barley, and perennial rye grass (*Lolium perenne* L.) in shortening plant height and increasing straw strength, while also maintaining yield and reducing lodging (Zagonel et al., 2002; Nolte, 2007; Penckowski et al., 2009; Dai et al., 2011). Zagonel et al. (2002) and Nolte (2007) reported an increase in stem diameter and straw strength following a TE treatment in common and durum wheat (*Triticum durum* Desf.). Field studies conducted by Dai et al., (2011), examined lodging and agronomic responses of wheat to TE. The wheat was treated with two application rates (119 g ha^{-1} and 240 g ha^{-1}) and three application timings. In general, their findings were that all application rates and timings were effective in decreasing plant height, improving straw strength, and reducing the amount of lodging when compared to the untreated control. An application of TE at 119 g ha^{-1} during the Zadoks growth stage 37 and 240 g ha^{-1} at growth stage 30 promoted lodging resistance while maintaining grain yield. This product has also been effective in crops such as perennial rye grass. In studies conducted by Silberstein et al. (2001), seed yield increased with increasing rates of TE up to the highest rate of 600 g ha^{-1}. Those plots averaged 25% more seed yield than untreated plots and lodging was also effectively controlled compared to the untreated plots. It was also evident that as the growth stages of the rye grass increased the higher rates of TE led to a negative effect on yield. Research conducted by Dunand (2003) and Unan et al. (2013)

indicated that rice grain yield was increased when TE was applied regardless of the rate. For both studies lodging was also decreased with TE application.

Each of these studies contributes to a better understanding of TE and the effects it has on different plant species. Additional research is needed to understand more completely the effects that TE has on rice. The objective of this study was to assess the effects of multiple TE rates and timings in combination with nitrogen (N) timings as a management practice to mitigate lodging for CL151, while still maintaining high yield potential. We hypothesize that TE will be effective in reducing plant height and decrease lodging potential; however there is concern about possible phytotoxic effects that high rates will have on the rice plant.

Materials and Methods

Site Description and Cultural Practices

Field studies were conducted at five different sites over a two year period. In 2012, research was conducted at the Delta Research and Extension Center (DREC), Stoneville, MS, on a Tunica clay (clayey over loamy, smectitic over mixed, superactive, nonacid, thermic Vertic Epiaquept) soil, and Mosco Farms, Shaw, MS, on a Forestdale silty clay loam (fine, smectitic, thermic Typic Endoaqualfs) soil. In 2013, the study was conducted at two DREC locations, both Sharkey clay soils (very-fine, smectitic, thermic Chromic Epiaquerts), and Hammett Farms, Greenville, MS, on a Commerce silt loam (fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts) soil. Soil textures were identified using the USDA-NRCS soil survey information compiled on the Web Soil Survey (USDA-NRCS, 2013). All important agronomic dates and events are presented in Table 3.1. CL151 was drill seeded using a Great Plains drill (Great Plains

Mfg., Inc. 1525 E. North Street, Salina, KS) at a rate of 90 kg ha^{-1} and grown in a delayed-flood culture. Seeding occurred on 2 April 2012 for Mosco and 10 April 2012 for DREC. In 2013, seeding occurred on 9 April and 30 April at DREC and 29 April for Hammet. A permanent flood was established at the 5- to -6- leaf growth stage and maintained until plant maturity and then drained approximately two weeks prior to harvest. The experimental units (plots) consisted of eight, 4.6 m rows spaced 20 cm apart. Each replication was separated by a 1.6 m alley. A factorial combination of TE rate (0, 12, 24, and 48 g ha^{-1}), TE timing [panicle differentiation (PD) or panicle differentiation + 14d (PD+14)] and N application strategies (100% applied preflood (PF) or 75% PF followed by 25% at PD) for a total of 16 treatments using Palisade® EC as the TE source. Treatments were arranged in a randomized complete block design and replicated four times. One hundred percent PF N rates were 202 and 168 kg N ha^{-1} on the clay and silt loam soils, respectively. Clay soils received a larger amount of total applied N due to N soil response recommendations by Walker et al. (2013). The PF N was applied with a custom-manufactured, self-propelled fertilizer distributor equipped with a Hege 80 belt cone (Wintersteiger, Inc., Salt Lake City, UT) and zero-max (Zero-Max, Inc., Plymouth, MN) to guarantee accuracy and precision. The PD application of N was broadcast by hand onto each plot into the flood water. Trinexapac-ethyl was applied with a CO_2 pressurized backpack sprayer calibrated to deliver a total spray volume of 23 L ha^{-1} using TeeJet 110015 AI tips. Plots were managed according to Buehring et al. (2008) to minimize pest pressure.

Data Collection

Plant samples of 0.9 m were taken at plant maturity from only the plots receiving 100% of total N PF to measure stem diameter and panicle length. Stem diameter was measured using a Mitutoyo caliper (Mitutoyo Corporation, Kanagawa, Japan). Panicle length was measured from the panicle base to the tip of the panicle, and plant height was measured from the soil surface to the top of the extended panicle at maturity. Two plants per plot were randomly selected for measurement to get an average plant height per plot. Immediately before harvest all plots were visually rated for lodging intensity on a scale of 1 to 5 (1=erect, 3= 45 degree angle, and 5= horizontal and matted to the ground) and lodging percent (a visual estimate of the percent of the total plot lodged). Plots were harvested when grain moisture for the latest maturing plots was below 220 g kg^{-1} with a Wintersteiger Delta small plot research combine (Wintersteiger, Inc., Salt Lake City, UT) equipped with a Harvest Master grain gauge (Juniper Systems, Inc., Logan UT). The Harvest Master system was used for measuring grain weight and moisture to calculate grain yield. A rough rice sample was collected from each test plot during harvest for milling analysis. Milling was conducted on a Zaccaria PAZ/1-DTA laboratory rice mill (Zaccaria USA, Anna, TX). Paddy rice (100 g) was subjected to a two-step process to determine the percent whole grains and total grains on a weight basis. Step one was that the paddy rice was hulled and polished for 67 seconds with the weight of total polished rice being recorded. Step two included the total polished rice being subjected to a slotted cylinder designed to separate whole polished kernels from broken polished kernels for an additional 67 seconds. The weight of whole kernels was then recorded.

Statistical Analysis

PROC MIXED (SAS, 2008) was used to test fixed effects and interactions among fixed effects. Data was pooled over multiple site years for similar soil types (clay soil or silt loam soil) and termed environments. Replication was considered a random effect, while TE rate, TE timing, and N management scheme were considered fixed effects. Analyzing the data based on similar soil types allows for conclusions to be made about treatments over a range of environments (Carmer et al., 1989). Analysis of variance was conducted for rice milling whole and total percent, panicle length, stem diameter, grain yield, and lodging percent and intensity. Least square means at the $P < 0.05$ was used for mean separation.

Results and Discussion

Lodging Percent and Lodging Intensity

For the silt loam locations, lodging intensity and lodging percent were affected by the main effect of TE rate (Table 3.2). Percent of the plot lodged was greatest (13%) when no TE was applied. Lodging was less when 12 (4%), 24 (1%), and 50 (0%) g ha^{-1} were applied compared to no application of TE (Table 3.4). Lodging intensity was greatest (1.5) when TE was not used, and decreased when TE was applied at any rate. These findings are similar to that of Dillon et al. (2010) and Unan et al. (2013) which also found TE rate affected lodging, and that lodging decreased with increasing TE rates. The results of our research indicate that there was no advantage to increasing the TE beyond 12 g ha^{-1} because lodging was not decreased with increasing rate of TE (Table 3.4).

The clay soil locations followed a similar trend for lodging intensity and percent of plot lodged; however, there was an interaction among the main effects of TE rate and

N application strategy (Table 3.3). The greatest lodging percentage (22%) and intensity (3) occurred when TE was not applied and 100% of the N was applied PF (Table 3.5). There was no lodging present when TE was not applied or when applied at 12, 24, and 48 g ha^{-1} and N was applied in 75/25 split application (Table 3.5). These findings are again similar to that of Dillon et al. (2010) and Unan et al. (2013), but differ from research performed on spring wheat by Dai et al. (2011) where a reduction of lodging only occurred when TE was applied at 240 g ha^{-1}. Previous research by Dunand (2003) was similar to results for both soil types, which found that not applying TE resulted in 38% lodging compared to 0 to 8% when TE was applied at any rate. Our research suggests on this soil type lodging can be managed simply by applying N in a split application, but if TE is applied with a split application of N, increased benefits are not seen with more than 12 g ha^{-1} of TE applied. If N is applied 100% PF no more than 24 g ha^{-1} is needed to significantly minimize the potential for lodging.

Plant Height

Plant height was affected by TE rate, TE timing, and N application strategy for silt loam soils (Table 3.2). Pooled over TE timing and N application scheme, as the rate of TE increased plant height decreased. A 13% reduction in plant height is found when 48 g TE ha^{-1} was used compared to no application of TE (Table 3.4). Dunand (2004) found reductions in plant height of 5 to 7 cm and Unan et al. (2013) indicated up to 43 cm decreases in that plant height when TE was increased. Trinexapac-ethyl timing and N application strategy were also factors that impacted plant height. Pooled over TE rates, plant height was greatest (97 cm) when TE was applied at PD compared to 94 cm when applied at PD + 14 (Table 3.6). Pooled over TE rate and application timing, plant height was 3 cm greater when N application occurred 100% PF compared to a split application (Table 3.6). Dai et al. (2011) also found that plant heights were reduced with a later application timing of TE in hard red spring wheat (*Triticum aestivum*).

Plant height was affected by N application timing and the interaction among TE rate and TE timing on clay soils (Table 3.3). Similar to silt loam soils, application timing of N affected plant height. When N was applied 100% PF plant height was 98 cm compared to 95 cm when the 75/25 split N application was used. The interaction of rate and timing of TE had an impact on plant height, and height was greatest when no TE was applied (102 cm) and shortest when 48 g TE ha^{-1} was applied at PD +14 (88 cm) (Table 3.7). Within the TE rates, heights were reduced 3 to 5 cm by applying TE at the later timing which is in agreement with previous research. (Dunand. 2003; Dillon et al. 2010; Unan et al. 2013). This data suggests that the highest rate of TE and the PD+14 application timing are the most effective in reducing plant height for both soils.

Milling Quality

Whole and total milled rice percentages for studies on silt loam soils were affected by N application timing, and were greater when N was applied 100% PF (Table 3.2 and Table 3.8). For clay soils, whole milled rice percent was affected by N management scheme (Table 3.3). Milling whole was 46.3% when N was applied 100% PF and decreased to 43.2% when N was applied in the 75/25 split (Table 3.8). The TE rate also had a very slight impact on milling totals for both soil types, data not shown.

Stem Diameter and Panicle Length

Rice stem diameter was not affected for either soil type (Table 3.2 and Table 3.3). Panicle length was affected by TE rate and timing for silt loam soils (Table 3.2). Applying TE at 48 g ha^{-1} caused the panicle length to be shorter (17.3cm) than when applied at 12 g ha^{-1} or not applied at all. Panicle length was 1 cm shorter when TE was applied at PD + 14 (Table 3.9). This research indicates that the highest rates and the later application timing shortened the plant internodes resulting in a shorter panicle length.

Grain Yield

Grain yield was affected by the interaction of TE rate and timing for silt loam soils (Table 3.2). Grain yield was greatest (13,175 kg ha^{-1}) when TE was not applied and decreased 15% (11,194 kg ha^{-1}) when 48 g ha^{-1} was applied at PD + 14. The interaction among the main effects was most evident when 48 g ha^{-1} of TE was applied at PD + 14, which led to a 7% decrease in yield when compared to the same rate at the PD timing (Table 3.10). These results differ from previous research which all reported TE increased rice grain yields (Dunand, 2004; Dillon et al., 2010; Unan et al., 2013). However, Dunand (2003) reported TE increased grain yield when compared to the control, but noted that when TE was applied at 31.36 g ha^{-1} and at the late boot plant growth stage, yield was decreased by 13%. Grain yield was not impacted when TE was applied at the lower rate. On this soil type, panicle length was also reduced when TE was applied at 48 g ha^{-1} and when applied at PD+14. Since panicle length contributes to yield potential, at least some of the grain yield reduction can be attributed to the reduction in panicle length.

Grain yield was affected by TE rate and N split on clay soils (Table 3.3). Grain yield was greatest (12,163 kg ha^{-1}) when TE was not applied and decreased with increasing TE rate to 11,422 kg ha^{-1} (Table 3.11) A grain yield loss of 6% occurred when 48 g ha^{-1} was applied. Dillon et al. (2010), Dunand, (2003 and 2004), and Unan et al., (2013) all had findings in disagreement with this study. However, Unan et al., (2013) did note that although applying TE improved grain yields, increased yield benefits were not observed with increasing rates of TE, which were similar to the results of this study. Nitrogen application scheme also significantly affected yield. Because our results differ from previous research it may indicate there is a TE and rice cultivar effect. Grain yield decreased 4% when N was applied in a 75/25 split compared to 100% PF (Table 3.11). Those findings were in agreement with both Walker et al. (2006) and Dillon et al. (2010) which reported higher grain yields when a single PF N is applied compared to a split application.

Conclusion

Trinexapac-ethyl is not currently labeled for use in rice production. These data showed that TE is effective in reducing plant height while also reducing lodging intensity and percent. However, grain yield was negatively impacted with high rates of TE. Applying 48 g ha^{-1} of TE decreased grain yields 15% for silt loam soils and 6% for clay soils. This indicated TE may have been phytotoxic to the plant when used at high rates, but it is also a possibility that TE reacts differently depending on the cultivar used. The referenced data suggest that lodging can be reduced by applying TE at 24 g ha^{-1} while maintaining 97% grain yield potential. Trinexapac-ethyl has potential to be used in rice production because of its ability to minimize lodging which would allow producers to continue using the high yielding cultivar CL151, while reducing the potential for lodging.

Table 3.1 Dates of agronomic management and treatment events for trinexapac-ethyl (TE) studies conducted in 2012 and 2013.

Event	2012	2013
Seeding†	2 April Mosco 10 April DREC	9 April DREC1 30 April DREC2 29 April Hammett
Emergence	9 April Mosco 19 April DREC	18 April DREC1 6 May DREC2 6 May Hammett
Pre-flood N treatments	17 May Mosco 18 May DREC	28 May DREC1 4 June DREC2 10 June Hammett
Flood established	20 May Mosco 11 May DREC	30 May DREC1 5 June DREC2 11 June Hammett
PD‡ N treatments	4 June Mosco 5 June DREC	17 June DREC1 20 June DREC2 19 June Hammett
PD TE applications	7 June both locations	17 June DREC1 21 June DREC2 17 June Hammett
PD + 14 TE applications	21 June both locations	2 July DREC1 3 July DREC2 2 July Hammett
Harvest	27 August Mosco 20 August DREC	18 September DREC1 30 September DREC2 13 September Hammett

† Seeding, CL151 at 90kg ha^{-1}

Table 3.2 Test of fixed effects and interactions on silt loam soils for three site years for plant height, percent of the plot lodged, lodging intensity, rice grain yield, milling whole and total, stem diameter, and panicle length.

Source	Plant Height	Lodging %	Lodge Intense	Grain Yield	Milling Total	Milling Whole	Stem Diam.	Panicle Length
				Pr > F				
TE Rate†	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	NS	NS	0.015
TE Timing‡	0.0059	NS	NS	0.0054	0.0034	NS	NS	0.0055
N Strategy§	0.0034	NS	NS	NS	0.0387	<0.0001	.	.
TE Rate x TE Timing	NS¥	NS	NS	0.0242	NS	NS	NS	NS
TE Rate x N Strategy	NS	NS	NS	NS	NS	NS	.	.
TE Timing x N Strategy	NS	NS	NS	NS	NS	NS	.	.
TE Rate x TE Timing x N Strategy	NS	NS	NS	NS	NS	NS	.	.

† TE rate, Trinexapac-ethyl application rate.
‡ TE timing, Trinexapac-ethyl application timing.
§ N application, Nitrogen application strategy.
¥ NS, not significant at the P = 0.05 level.

Table 3.3 Test of fixed effects and interactions on clay soils for three site years for plant height, percent of the plot lodged, lodging intensity, rice grain yield, milling whole and total, stem diameter, and panicle length.

Source	Plant Height	Lodging %	Lodging Intensity	Grain Yield	Milling Total	Milling Whole	Stem Diam	Panicle Length
				Pr > F				
TE Rate†	<0.0001	<0.0001	<0.0001	0.0005	0.0308	NS	NS	NS
TE Timing‡	0.0003	NS	NS	NS	NS	NS	NS	NS
N Strategy§	<0.0001	<0.0001	<0.0001	0.0001	NS	0.0001	.	.
TE Rate x TE Timing	0.0089	NS	NS	NS	NS	NS	NS	NS
TE Rate x N Strategy	NS¥	0.0001	0.005	NS	NS	NS	.	.
TE Timing x N Strategy	NS	NS	NS	NS	NS	NS	.	.
TE Rate x TE Timing x N Strategy	NS	NS	NS	NS	NS	NS	.	.

† TE rate, Trinexapac-ethyl application rate.

‡ TE timing, Trinexapac-ethyl application timing.

§ N application, Nitrogen application strategy.

¥ NS, not significant at the P = 0.05 level.

Table 3.4 Rice plant height, percent of plot lodged, and lodging intensity (1-5) for silt loam soils as affected by trinexapac-ethyl (TE) rate pooled over nitrogen management scheme and TE timing.

TE Rate (g ha^{-1})	Height (cm)	Plot lodged (%)	Lodging Intensity (1-5)
0	102 A‡	13 A‡	1.5 A‡
12	99 B	4 B	1.2 B
24	94 C	1B	1.1 B
48	89 D	0 B	1.0 B

‡ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$

Table 3.5 Lodging intensity (1-5) and percent of plot lodged as affected by the interaction of trinexepac-ethyl (TE) rate and nitrogen scheme {100% applied pre-flood or 75% applied pre-flood followed by 25% at panicle differentiation) pooled over TE timing for clay soils.

TE Rate (g ha^{-1})	Nitrogen Strategy	Plot lodged (%)		Lodge score (1-5)	
0	100	22	A‡	2.9	A‡
0	75/25	2	BCD	1.5	BC
12	100	8	B	1.7	B
12	75/25	0	D	1	D
24	100	6	BC	1.7	B
24	75/25	0	D	1	D
48	100	1	CD	1.1	CD
48	75/25	0	D	1	D

‡ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$.

Table 3.6 Rice plant height for silt loam soils as affected by trinexapac-ethyl timing {applied at panicle differentiation (PD) or PD+14 days} and nitrogen (N) management scheme {100% applied preflood or 75% applied pre-flood followed by 25% at panicle differentiation} pooled over two site years.

TE Timing	Height	
PD	97	A‡
PD+14	94	B
Nitrogen Strategy		
100	97	A
75/25	94	B

‡ Means followed by same letter for each effect are not significantly different $P \leq 0.05$.

Table 3.7 Rice plant height for clay soils as affected by the interaction of trinexapac-ethyl rate and TE timing {applied at panicle differentiation (PD) or PD+14 days} pooled over nitrogen management scheme, and plant height as affected by nitrogen (N) management scheme {100% applied pre-flood or 75% applied pre-flood followed by 25% at panicle differentiation} pooled over TE rate and timing.

TE Rate (g ha^{-1})	TE Timing	Plant Height (cm)	
0	PD	101	AB‡
0	PD+14	102	A
12	PD	100	BC
12	PD+14	97	C
24	PD	98	C
24	PD+14	93	D
48	PD	93	D
48	PD+14	88	E
Nitrogen Strategy			
100	.	98	A‡
75/25	.	95	B

‡ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$.

Table 3.8 Whole and total milling as affected by nitrogen (N) application scheme {100% applied pre-flood or 75% applied pre-flood followed by 25% at panicle differentiation} pooled over trinexapac-ethyl rate and timing for clay and silt loam soils.

Nitrogen Application Scheme	Silt Loam Milling Total† %	Silt Loam Milling Whole† %	Clay Milling Total† %	Clay Milling Whole† %
100	70.9 A‡	58.2 A‡	69.8 A‡	46.3 A‡
75/25	70.7 B	55.6 B	69.8 A	43.2 B

‡ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$.

Table 3.9 Rice panicle length as affected by trinexapac-ethyl rate pooled over nitrogen management scheme and TE timing, and TE timing {applied at panicle differentiation (PD) or PD+14 days} pooled over nitrogen management scheme and TE for silt loam soils.

TE Rate (g ha^{-1})	Panicle Length (cm)	
0	18.5	A‡
12	18.9	A
24	18.0	AB
48	17.3	B
TE Timing		
PD	18.7	A
PD+14	17.7	B

‡ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$.

Table 3.10 Rice grain yield for silt loam soils as affected by the interaction of trinexapac-ethyl (TE) rate and TE application timing {applied at panicle differentiation (PD) or PD+14 days} pooled over nitrogen management scheme.

TE Rate (g ha^{-1})	TE Timing	Yield (kg per ha^{-1})	
0	PD+14	13175	A‡
0	PD	13091	AB
12	PD	12784	ABC
12	PD+14	12674	BC
24	PD	12500	CD
24	PD+14	12086	D
48	PD	12076	D
48	PD+14	11194	E

‡ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$.

Table 3.11 Rice grain yield for clay soils as affected by trinexapac-ethyl (TE) rate and nitrogen (N) management scheme {100% applied pre-flood or 75% applied pre-flood followed by 25% at panicle differentiation} pooled over TE timing.

TE Rate ($g\ ha^{-1}$)	Grain Yield ($kg\ ha^{-1}$)	
0	12163	A‡
12	11823	B
24	11841	AB
48	11422	C
Nitrogen scheme		
100	12083	A
75/25	11542	B

‡ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$.

Literature Cited

Anonymous, 2012. Horizon Ag. www.horizonseed.com/clearfield-varieties. Date verified July 2, 2012

Blanche, S.B., X. Sha, D.L. Harrell, D.E. Groth, K.F. Bearb, L.M. White, and S.D. Linscombe. 2011. Registration of ‘CL151’ rice. Journal of Plant Registrations, Vol. 5, No. 2, May 2011 p.177^{-1}80

Buehring, N. 2008. Mississippi rice growers’ guide. P. 4. Mississippi State Extension publication 2255.

Carmer, S. G., W. E. Nyquist, and W. M. Walker. 1989. Least significant differences for combined analysis of experiments with two or three-factor treatment designs. Agron. J. 81:665–672.

Dai., J. and J.J. Wiersama. 2011. Agronomic responses and lodging of three spring wheat cultivars to trinexipac-ethyl. Online. Crop Management doi:10.1094/CM^{-} ^{2}011-0517-01-RS.

Dillon, K.A., T.W. Walker, C.H. Koger, and J.J. Varco. 2010. Evaluation of Trinexapac-Ethyl to Reduce Lodging for Hybrid Rice. Poster abstract submitted. Rice Tech. Working Group Meeting. Biloxi, MS.

Dunand, R.T. 2003. Influence of growth suppression on stature reduction, panicle development, and crop production in rice. PGRSA Qrtly 31(2):96.

Dunand, R.T. 2004. Trinexapac-ethyl, plant population, nitrogen fertility, and crop production in drill-seeded rice. PGRSA Quarterly 32(2):48.

Kanter, D.G., T.W. Walker, N.W. Buehring, W. L. Soloman, L.S. Lanford, S. Shaifer, P. Fitts, and J.L. Corbin. 2011. Mississippi rice variety trials. Mississippi Agriculture & Forestry Experiment Station publication.

Moldenhaur, K.A.K., J.W. Gibbons, F.N. Lee, R.J. Norman, J.L. Bernhardt, M.A. Anders, C.E. Wilson, N.A. Slaton, J.N. Rutger, T. Tain, R. Bryant, M.M. Blocker, and A.C. Tolbert. 2001. Breeding and evaluation for improved rice varieties: The Arkansas rice breeding and development program. In R.J. Norman and J.F. Meullenet (ed.) B.R. Wells Rice Res. Studies 2000. Univ of Arkansas Agric. Exp. Stn. Res. Ser. 485:20^{-2}6.

Nolte. K. 2007. The PGR trinexipac-ethyl reduces lodging in desert durum wheat. HortScience 42:865-866.

Ottis, B.V., and R.E. Talbert. 2005. Rice yield components as affected by cultivar and seeding rate. Agron. J. 97:1622^{-1}625.

Pencowski, L.H., J. Zagonel, and E.C. Fernandes. 2009. Nitrogen and growth reducer in high yield wheat. Acta Sci. Agron. 31:473-479

Salassi, M.E., M.A. Deliberto, S.D. Linscombe, C.E. Wilson, Jr., T.W. Walker, G.N. McCauley, and D.C. Blouin. 2013. Impact of harvest lodging on rough rice milling yield and market price. Agron. J. 105:1860^{-1}867.

Silberstein, T.B., W.C. Young III, T.G. Chastain, and C.J. Garbacik. 2001. Response of cool season grasses to foliar applications of palisade (trinexapac-ethyl) plant growth regulator.

Street, J. E., and P.K. Bollich (2003). Rice production. P. 271^{-2}96. In C. Wayne Smith and Robert H. Dilday (ed.) Rice: Origin, History, Technology, and Production. John Wiley & Sons, Hoboken, New Jersey.

Unan, R., I. Sezer, M. Sahin, and L.A.J. Mur. 2013. Control of lodging and reduction in plant length in rice (Oryza sativa L.) with the treatment of trinexapac-ethyl and sowing density. Turk. J. 37:257^{-2}64.

United States Department of Agriculture. USDA. 2013. United State Department of Agriculture. Crop values 2012 summary. Nat. Agric. Statistics Serv., Washington, D.C.

United States Department of Agriculture, National Resources Conservations Services. USDA-NRCS. 2013. Web soil survey. Available at http://websoil.survey.nrcs.usda.gov/app/WebSoilSurvey.aspx (verified 18 December 2013). USDA-NRCS, Washington, DC.

Walker, T.W., R.L. Atwill, J.L. Corbin, P.W. Fitts, L.S. Lanford, and S.D. Shaifer. 2013. Mississippi rice variety trials. Miss. Agric. and For. Exp. Stn. Information Bulletin No. 481. Mississippi State, MS.

Walker, T.W., S.W. Martin., and P. Gerard. 2006. Grain yield and milling quality response of two rice cultivars to top-dress nitrogen application timings. Agron. J. 98:1495^{-1}500.

Wopereis-Pura, M.M., M.C.S. Wopereis, J. Moreira, and H. Watanabe. 2002. Effect of late nitrogen application on rice yield, grain quality, and profitability in the Senegal River Valley. Eur. J. Agron. 17:191^{-1}98.

Zagonel, J., W.S. Venancio, and R.P. Kunz. 2002. Effect of growth regulator on wheat crop under different nitrogen rates and plant densities. Planta Daninha 20:471-476.

CHAPTER IV

EVALUATION OF POTASSIUM RATES AND TIMINGS AND FUNGICIDE APPLICATION TIMINGS WITH NITROGEN MANAGEMENT PRACTICES TO MINIMIZE LODGING FOR 'CL151'

Abstract

'CL151' a Clearfield® (BASF, Ludwigshafen, Germany) long-grain rice cultivar, developed by LSU AgCenter Rice Research Station (RRS) in Crowley, LA, was released in 2008 based upon excellent agronomic characteristics, including a moderately resistant to lodging rating. Further research indicated it is very susceptible to lodging. Lodging can reduce harvest efficiency, yield, and cause grain quality loss. CL151 continues to account for a considerable portion of the planted acreage because it can be treated to control red rice and provides excellent yield potential. Two separate field experiments were conducted in both 2011 and 2012 on two soil types in Mississippi to determine management practices to minimize lodging potential for CL151. Study 1 consisted of a factorial combination of N rate (112 or 224 kg N ha^{-1}), K rate (0, 51, 101, or 152 kg K_20 ha^{-1}), and K application timing [pre-flood (PF) or panicle initiation (PI)]. Study 2 consisted of a factorial combination of N rate (112 or 224 kg N ha^{-1}), K rate (0, 68, or 135 kg K_20 ha^{-1}), and fungicide timing [panicle differentiation (PD) or boot]. Treatments for both experiments were arranged in a randomized complete block design and replicated four times. Quadris® [azoxystrobin {methyl $(E)^{-2}$-[2[6-(2-cyanophenoxy) pyrimidin-

4yloxy] phenyl]-3- methooxyacrylate}] was applied at 0.22 kg a.i. ha^{-1}. Response variables were lodging area, lodging intensity, plant height, and grain yield. In both studies, rice grain yields for CL151 were greatest with a PF N rate of 224 kg N ha^{-1}. However, N rate also largely influenced lodging percent and intensity. Lodging was greater on the silt loam soils between the two N rates; however, yields differnces were typically less than 5%. Application of the fungicide on silt loam soils increased grain yield and decreased, but did not eliminate lodging percent and intensity when applied with 224 kg N ha^{-1}. Potassium application in the soil environments in which these studies were conducted did not affect lodging or grain yield potential.

Introduction

'CL151' (Reg. No. CV-133, PI 654463), a Clearfield® (BASF, Ludwigshafen, Germany) long-grain rice cultivar, was developed by the LSU AgCenter at the Rice Research Station in Crowley, LA. It was approved for release in 2008 based upon superior agronomic characteristics such as herbicide resistance, high yield potential, good milling quality, and improved disease resistance (Blanche et al., 2011). This cultivar is susceptible to sheath blight (Rhizoctonia solani), a disease that spreads to the culm of the plant and can cause the tillers to lodge (Blanche et al., 2011). CL151 has a semi-dwarf growth habit, and Blanche et al. (2011) originally released it as rated moderately resistant to lodging. However, further research has demonstrated it to be very susceptible to lodging (Anonymous, 2012). Lodging is a negative characteristic in rice; however, this cultivar has remained popular because of its excellent yield potential and tolerance to Beyond® and Newpath® herbicides. These herbicides are important for control of red rice. In Mississippi, CL151 provided 20% greater yield compared to 'CL131', (patent number US 7 786 360 B2) a lodging resistant cultivar, (Kanter et al., 2011), and accounted for approximately 10% of the planted hectarage in Mississippi in 2012 and 2013 (Walker et al., 2013)

Lodging is the permanent displacement of stems from the vertical angle. This leads to the crop having a permanent lean or lying horizontally on the ground. Stem lodging results from the buckling of any part of the stem, and is the type of lodging that occurs most often in CL151 (Berry et al., 2006). Lodging can create many problems for harvest, including decreased harvest efficiency, reduced grain quality, and the potential for reduced yield (Walker et al. 2008). Factors that affect lodging are nitrogen (N) supply, potassium (K) nutrition, and fungicide application (Bhiah et al., 2010).

Nutrient uptake in rice is similar to upland row crops such as corn (Zea mays) and wheat (Triticum aestivum). However, the flooded environment where rice is grown impacts nutrient behavior and availability in the soil. This environment alters the way fertilizers are applied relative to upland grown crops to maximize plant uptake and growth (Norman et al., 2003). Nitrogen is absorbed by rice in two different chemical forms, ammonium (NH_4^+) and nitrate (NO_3^-). Ammonium moves through the soil solution mostly by diffusion, whereas nitrates move by both mass flow and diffusion. The lack of oxygen in the flooded soil results in anaerobic conditions that cause NH_4^+ to be stable and accumulate in the soil; whereas, NO_3^- is unstable in this environment and can be converted to N_2 gas. Potassium (K) availability to rice increases after flooding due to exchangeable K^+ being displaced from the soil exchange complex into the soil solution by the NH_4^+ that was applied earlier in the season, and K is believed to remain relatively constant under flooded conditions (Norman et al., 2003).

Nitrogen is the nutrient applied the most frequently and in the greatest quantity in rice production. However, there are other nutrients such as K that are also important to the rice plant (Norman et al., 2003). Potassium deficiency has not been a common problem in Mississippi rice production due to the relatively high levels of native K in alluvial soils. Potassium is absorbed by rice in the K^+ form and its concentration in the plant is greatest during the seedling stage and decreases as the plant accumulates dry matter (Sims and Place 1968; Norman et al., 2003). Approximately one-half of the total K present at physiological maturity is absorbed by panicle differentiation, so a large percentage of K is absorbed during reproductive growth. Accumulation of K reaches a peak around 50% heading and then slowly begins to decline (Norman et al., 2003).

Potassium nutrition is vital to minimize susceptibility to plant diseases such as brown spot (Bipolaris oryzae L.) and stem rot (Sclerotium orzyae L.) (Huber and Arny, 1985; Slaton et al., 1995; Maschmann et al., 2010). Stem rot is the greatest concern because it infects the leaf sheath and the culms of the rice. Those two factors cause reduced straw strength which results in increased lodging incidence, and can reduce yield by up to 75% (Webster and Gunnell, 1992; Maschmann et al., 2010,). Research has shown that proper K fertilization can have a dramatic impact on the occurrence of stem rot (Cralley, 1938; Adair and Cralley, 1950; Jain 1976; Jayaraj et al., 1991; Maschmann et al., 2010), and there are fungicides available, such as azoxystrobin {methyl $(E)^{-2}$-[2[6-(2-cyanophenoxy) pyrimidin-4yloxy] phenyl]-3- methooxyacrylate} to reduce the incidence of disease. This fungicide does not completely control stem rot, but may suppress its development when applied to control sheath blight (Maschmann et al., 2010).

Not only is K an essential element in growing rice, but it has shown to be effective in reducing lodging incidence in crops such as wheat and corn. Liebhardt et al. (1976) found that KCl applied to corn reduced lodging due to lower disease incidence aided by K application (Liebhardt et al., 1976). Usherwood et al. (1975) had similar results with plant lodging due to stalk deterioration and disease infestation in corn and wheat. When 134 kg K_2O ha^{-1} was applied, yields increased and lodging decreased. Bhiah et al. (2010) conducted studies on two semi-dwarf rice cultivars under high N input conditions, and analyzed K application on plant lodging and growth. Applications of K significantly increased tiller number, plant height, and stem diameter. Lodging did occur, however, and it was due mostly to poor root growth in the absence of K. Nitrogen application promoted vegetative growth and plant height, and without supplemental additions of K, lodging increased. When a K deficiency was observed stem strength and diameter were reduced as well as a reduction in the number of tillers and plant height. In the cultivar Amber 13, a 32% increase in stem thickness and a 30% increase in upper stem strength was realized when K was applied. This experiment showed that the application of K can reduce the occurrence of lodging in the presence of high N supply (Bhiah et al., 2010).

Previous research has indicated that K application and fungicide application may reduce lodging incidence. The objective of this research was to evaluate how various combinations of K rates and application timings and K rates and fungicide timings influence lodging, plant height, and yield for CL151.

Materials and Methods

Site Description and Cultural Practices

Research was established over a two year period. In 2011, research was conducted at the Delta Research and Extension Center (DREC), Stoneville, MS on a Tunica clay (clayey over loamy, smectitic over mixed, superactive, nonacid, thermic Vertic Epiaquept) soil, and Mosco Farms, Shaw, MS on a Dundee silty clay loam (fine, smectitic, thermic Typic Endoaqualfs) soil. In 2012, research was conducted at DREC, on a Tunica clay soil, and Mosco Farms, Shaw, MS on a Forestdale silty clay loam (fine, smectitic, thermic Typic Endoaqualfs) soil. Soil textures were identified using the USDA-NRCS soil survey information compiled on the Web Soil Survey (USDA-NRCS, 2013).

Experiment 1 consisted of a factorial combination of N rates (112 or 224 kg N ha^{-1}), K rates (0, 51, 101, or 152 kg K_20 ha^{-1}), as well as K application timings preflood (PF) and panicle initiation (PI). Experiment 2 consisted of a factorial combination of N rates (112 or 224 kg N ha^{-1}), K rates (0, 68, or 135 kg K_20 ha^{-1}), and fungicide timings [none, panicle differentiation (PD), and boot]. Quadris® which contains azoxystrobin {methyl (E)-2-[2[6-(2-cyanophenoxy) pyrimidin-4yloxy] phenyl]-3- methooxyacrylate} (Syngenta Crop Protection Inc., Greensboro, NC), as the active ingredient was used as the fungicide source. All important agronomic dates and events are listed in Table 4.1 for Experiment 1 and Table 4.2 for Experiment 2.

In both experiments, CL151 was drill seeded using a Great Plains drill (Great Plains Mfg., Inc. 1525 E. North Street, Salina, KS) at a rate of 90 kg ha^{-1} and grown in a delayed-flood culture. In 2011, seeding occurred on 4 April for DREC and 9 April for

Mosco. Seeding occurred on 2 April 2012 for Mosco and 10 April 2012 for DREC. A permanent flood was established at the 5- to 6-leaf growth stage and maintained until draining occurred approximately two weeks prior to harvest. Experimental units (plots) consisted of eight, 4.6-m rows spaced 20-cm apart. Each replication was separated by a 1.6-m alley. Treatment combinations were arranged in a randomized complete block design and replicated four times. The PF N and K were applied with a custom-manufactured, self-propelled fertilizer distributer equipped with a Hege 80 belt cone (Wintersteiger, Inc., Salt Lake City, UT) and zero-max (Zero-Max, Inc., Plymouth, MN) to guarantee accuracy and precision. The PI application of K was broadcast by hand onto each plot into the flood water. Quadris® was applied at 0.22 kg a.i. ha^{-1} with backpack sprayer equipped with TeeJet 110015 air induction tips (TeeJet Technologies, Wheaton, IL 60187). Plots were managed according to Buehring et al. (2008) to minimize pest pressure.

Data Collection

Plant height was measured from the soil surface to the top of the extended panicle at maturity to evaluate possible plant responses to different treatments. Two plants per plot were randomly selected to determine an average plant height per plot. Immediately before harvest all plots were visually rated for lodging intensity on a scale of 1 to 5 (1=erect, 3= 45 degree angle, and 5= horizontal and matted to the ground) and lodging percent (a visual estimate of the percent of the total plot lodged). Plots were harvested when grain moisture for the latest maturing plots was below 220 g kg^{-1} with a Wintersteiger Delta small plot research combine (Wintersteiger, Inc., Salt Lake City, UT) equipped with a Harvest Master grain gauge (Juniper Systems, Inc., Logan UT). The

Harvest Master system was used for measuring grain weight and moisture to calculate grain yield, which was standardized to 120 g kg^{-1} moisture content for analysis.

Statistical Analysis

PROC MIXED (SAS, 2008) was used to test fixed effects and interactions among fixed effects. Data for each study was pooled over multiple site years for similar soil types (clay soil or silt loam soil) and termed environments. Replication nested within environment were considered random effects for both studies. Considering site year within a soil type a random effect allows for conclusions to be made about treatments over a range of environments (Carmer et al., 1989). Nitrogen rate and K rate were considered fixed effects in both studies, while K timing and fungicide application timing were considered fixed effects for Experiment 1 and Experiment 2, respectively. Analysis of variance was conducted for plant height, grain yield, and lodging percent and intensity. Least square means at the $P < 0.05$ was used for mean separation.

Results and Discussion

Lodging Percent and Lodging Intensity

For silt loam and clay soils, percent of plot lodged was impacted by N rate for Experiment 1 (Table 4.3 and Table 4.4). Lodging occurred when 224 kg N ha^{-1} was applied (Table 4.5 and Table 4.6). For silt loam soil, lodging intensity was affected by the interaction of N rate and K rate (Table 4.5). At 224 kg N ha^{-1}, lodging intensity differed with K rate; however, there was no apparent trend with respect to K rate (Table 4.7). Conversely, Bhiah et al. (2010), found that supplemental K rates decreased lodging area and intensity when produced under high N fertilization.

In Experiment 2, conducted on silt loam soils, lodging percent and intensity were impacted by an interaction among the main effects of N rate and fungicide application timing (Table 4.8). When N was applied at 112 kg N ha^{-1}, minor lodging was observed regardless of fungicide application timing. Percent of plot lodged and intensity were greatest when 224 kg N ha^{-1} was applied with no fungicide application (Table 4.9). However, both lodging area and intensity were less within the greater N rate when fungicide was applied (Table 4.9). Similar to Experiment 1, lodging percent and intensity were only affected by N rate for Study 2 conducted on clay soil (Table 4.10). Lodging area was 27%, with an intensity score of 2.3, when N was applied at 224 kg N ha^{-1} (Table 4.11). Bhiah et al. (2010), also observed that rice was more susceptible to lodging when high rates of N was applied.

Rice response to K in Mississippi has not been documented. This is likely due to the fact that most soils in this region range from medium to high plus with respect to extractable K (Buehring et al. 2008). The soil testing where these experiments were conducted tested high to very high for extractable K. That is a possible reason why we did not observe an apparent K response or trend with respect to lodging and Bhiah et al. (2010) did. Bhiah et al. (2010) suggests they were researching soils that were K deficient, which is likely why they observed such a great response with root growth and lodging. Nitrogen applied at increased rates can cause increased leaf material within the rice plant. Experiment 2 on the silt loam soil did have a response to fungicide application when N was applied at the highest rate. Only minor sheath blight pressure was observed. The excessive N rate for this soil type possibly led to disease pressure which was controlled by the fungicide application.

Plant Height

In Experiment 1, plant height was affected by N rate on both silt loam and clay soils (Table 4.3 and Table 4.4). Plant height was 98 cm and 100 cm when 224 kg N ha^{-1} was applied and 91 cm and 89 cm when 112 kg N ha^{-1} was applied to silt loam and clay soils, respectively (Table 4.10 and Table 4.11). This is in agreement research conducted by Slaton et al. (2003) which stated that high rates of PF N can result in increased height and thickness of vegetative growth.

In Experiment 2, conducted on silt loam soils, plant height was also affected by N rate (Table 4.8). When N was applied at 112 kg N ha^{-1} and 224 kg N ha^{-1} plant height was 99 cm and 104 cm, respectively (Table 4.12). For Experiment 2 conducted on clay soils, plant height was affected by an interaction of N rate and K rate (Table 4.10). When N was applied at 112 kg N ha^{-1} plant height was 94 cm, however when N was applied at 224 kg N ha^{-1}, plant height was greatest (104 cm) when 135 kg K_2O ha^{-1} was applied (Table 4.13).

Grain Yield

The main effect N rate for Experiment 1 conducted on silt loam and clay soils impacted grain yield (Table 4.3 and Table 4.4). The same was true for Experiment 2 conducted on clay soils (Table 4.10). Grain yields for the largest N rate were approximately 4% greater compared to the low N rate on silt loam soils, but were approximately 25% greater with the high N rate on clay soils (Table 4.11 and Table 4.12). This is in agreement with multiple studies which have all indicated that N rate is one of the most important components impacting rice grain yield (Harrell et al., 2011; Walker et al., 2006; Griggs et al., 2007; Harrell et al., 2009).

Experiment 2 conducted on silt loam was affected by the main effects N rate and fungicide application timing (Table 4.8). Grain yield was greatest (13,139 kg ha^{-1}) when N was applied at 224 kg ha^{-1} (Table 4.12). With respect to fungicide application timing, grain yield was 12,660 and 12,789 kg ha^{-1} when the fungicide was applied at PD and Boot respectively, and both application timings produced greater yields when compared to no fungicide application (Table 4.12). The interaction is not significant, but data suggests that the increase in yield is possibly due to the decreased lodging that occurred at the 224 kg N ha^{-1} rate and PD or Boot fungicide application. Mascchmann et al. (2010) and Slaton et al. (2003) also found that grain yields were increased with application of fungicide, and believed that it was possibly due to the fact the fungicide aided in controlling multiple diseases that might cause yield reduction.

Rice grain yield response to high N input is well documented (Buering et al. 2008; Walker et al. 2008). Walker et al. (2008) reported varying N response curves based on soil type which helps to explain the dramatic differences in grain yield for each soil type. Clay soils have a much higher affinity for NH4+ than silt loam soils, and therefore require much more PF N to produce similar yields.

Conclusion

These studies suggest lodging area and intensity for CL151 was largely influenced by N rate. Plant height and grain yield were also most responsive to N rate. On silt loam soils, greater lodging was observed between the two N rates; however, differences in yield were typically less than 5%. A fungicide application at the high N rate on silt loam soils decreased the amount of lodging. Therefore, CL151 can be fertilized with N to achieve approximately 95% of the relative grain yield potential with minimal lodging. However, if N rates are applied for near maximum achievable yield, a fungicide application during reproductive growth can decrease, but not offset lodging potential and also provide greater yields. Potassium application in the soil environments in which these studies were conducted did not affect lodging nor grain yield potential.

Table 4.1 Dates of agronomic management and treatment events for studies analyzing nitrogen (N) rate, potassium (K) rate, and K timings conducted in 2011 and 2012.

Event	2011	2012
Seeding†	9 April Mosco 1 April DREC	2 April Mosco 10 April DREC
Emergence	19 April Mosco 12 April DREC	9 April Mosco 19 April DREC
Pre-flood N and K treatments	13 May Mosco 5 May DREC	7 May Mosco 18 May DREC
Flood established	15 May Mosco 6 May DREC	20 May Mosco 11 May DREC
Application of PI‡ K	9 June Mosco 9 June DREC	1 June Mosco 1 June DREC
Harvest	17 August Mosco 23 August DREC	27 August Mosco 20 August DREC

† Seeding, CL151 at 90kg ha^{-1}
‡ Panicle initiation growth stage

Table 4.2 Dates of agronomic management and treatment events for nitrogen (N) rate, potassium (K) rate, and fungicide application timing studies conducted in 2011 and 2012.

Event	2011	2012
Seeding†	9 April Mosco 1 April DREC	2 April Mosco 10 April DREC
Emergence	19 April Mosco 12 April DREC	9 April Mosco 19 April DREC
Pre-flood N and K treatments	13 May Mosco 5 May DREC	7 May Mosco 18 May DREC
Flood established	15 May Mosco 6 May DREC	20 May Mosco 11 May DREC
Fungicide PD‡ application	9 June Mosco 9 June DREC	7 June Mosco 7 June DREC
Fungicide Boot application	23 June Mosco 23 June DREC	21 June Mosco 21 June DREC
Harvest	17 August Mosco 23 August DREC	27 August Mosco 20 August DREC

† Seeding, CL151 at 90kg ha^{-1}

‡ Panicle differentiation growth stage

Table 4.3 Test of fixed effects and interactions on silt loam soils for grain yield, plant height, percent of the plot lodged, and lodging intensity.

Source	Grain Yield	Lodging %	Lodging Intensity	Plant Height
	Pr > F			
N Rate†	<0.0001	<0.0001	<0.0001	<0.0001
K Rate‡	NS¥	NS	NS	NS
N x K Rate	NS	NS	NS	NS
K timing§	NS	NS	NS	NS
N rate x K timing	NS	NS	NS	NS
K rate x K timing	NS	NS	NS	NS
N rate x Ktiming x Krate	NS	NS	NS	NS

† N rate, Nitrogen application rate.
‡ K rate, Potassium application rate.
§ K timing, Potassium application timing.
¥ NS, not significant at the P = 0.05 level

Table 4.4 Test of fixed effects and interactions on clay soil for grain yield, plant height, percent of the plot lodged, and lodging intensity.

Source	Grain Yield	Lodging %	Lodging Intensity	Plant Height
	Pr > F			
N rate†	<.0004	<.0001	<.0001	<.0001
K rate‡	NS¥	NS	NS	NS
N x K rate	NS	NS	0.0141	NS
K timing§	NS	NS	NS	NS
N rate x K timing	NS	NS	NS	NS
K rate x K timing	NS	NS	NS	NS
N rate x K timing x K rate	NS	NS	NS	NS

† N rate, Nitrogen application rate.
‡ K rate, Potassium application rate.
§ K timing, Potassium application timing.
¥ NS, not significant at the P = 0.05 level

Table 4.5 Lodging score {1 to 5, 1= erect and 5= horizontal and matted to the ground} as affected by the interaction of N rate and K rate pooled over K timing for silt loam soils.

Nitrogen Rate (kg ha^{-1})	K Rate (kg ha^{-1})	Lodging Score (1-5)
112	0	1.0 A‡
112	51	1.0 A
112	101	1.0 A
112	152	1.0 A
224	0	1.8 B
224	51	3.0 D
224	101	2.5 CD
224	152	2.0 BC

‡ Means followed by same letter are not significantly different $P \leq 0.05$.

Table 4.6 Test of fixed effects and interactions on silt loam soil for grain yield, plant height, percent of the plot lodged, and lodging intensity.

Source	Grain Yield	Lodging %	Lodging Intensity	Plant Height
	Pr > F			
N rate†	<0.0001	<0.0001	<0.0001	<0.0001
K rate‡	NS¥	NS	NS	NS
N rate x K rate	NS	NS	NS	NS
Fungicide Timing§	0.0107	0.017	0.0264	NS
N rate x Fungicide Timing	NS	0.0428	0.0128	NS
K rate x Fungicide Timing	NS	NS	NS	NS
N rate x K rate x Fungicide Timing	NS	NS	NS	NS

† N rate, Nitrogen application rate.
‡ K rate, Potassium application rate.
§ Fungicide timing, Fungicide application timing.
¥ NS, not significant at the P = 0.05 level

Table 4.7 Lodging score {1 to 5, 1= erect and 5= horizontal and matted to the ground}, and percent of plot lodged as affected by the interaction of N rate and fungicide application timing pooled over potassium rate for silt loam soils.

Nitrogen Rate (kg ha^{-1})	Fungicide Application Timing	Lodging Score (1-5)	Lodging %
112	None	1.1 A‡	3.0 A
112	PD	1.1 A	2.0 A
112	Boot	1.1 A	3.0 A
224	None	2.8 C	39.0 C
224	PD	1.8 B	18.0 B
224	Boot	2.1 B	25.0 B

‡ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$.

Table 4.8 Test of fixed effects and interactions on clay soil for grain yield, plant height, percent of the plot lodged, and lodging intensity.

Source	Grain Yield	Lodging %	Lodging Intensity	Plant Height
	Pr > F			
N rate†	<0.0001	<0.0001	<.00001	<0.0001
K rate‡	NS¥	NS	NS	NS
N rate x K rate	NS	NS	NS	0.0289
Fungicide Timing§	NS	NS	NS	NS
N rate x Fungicide Timing	NS	NS	NS	NS
K rate x Fungicide Timing	NS	NS	NS	NS
N rate x K rate x Fungicide Timing	NS	NS	NS	NS

† N rate, Nitrogen application rate.
‡ K rate, Potassium application rate.
§ Fungicide timing, Fungicide application timing.
¥ NS, not significant at the P = 0.05 level

Table 4.9 Lodging score {1 to 5, 1= erect and 5= horizontal and matted to the ground}, lodging percent {percent of the total plot lodged}, and rice grain yield as affected by N rate pooled over potassium rate and fungicide timing for clay soils.

Nitrogen Rate (kg ha^{-1})	Lodging Score (1-5)	Lodging %	Grain Yield (kg ha^{-1})
112	1.0 A‡	1.0 A	9509 A
224	2.3 B	27.0 B	11420 B

‡ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$.

Table 4.10 The effect of nitrogen (N) rate on rice plant height, lodging percent {percent of the total plot lodged}, and rice grain yield pooled over potassium rate and application timing on silt loam soils.

Nitrogen Rate (kg ha^{-1})	Plant Height (cm)	Lodging %	Grain Yield (kg ha^{-1})
112	91 A‡	0 A	12828 A
224	98 B	36 B	13358 B

‡ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$.

Table 4.11 The effect of nitrogen (N) rate on rice plant height, lodging score {1 to 5, 1= erect and 5= horizontal and matted to the ground}, lodging percent {percent of the total plot lodged}, and rice grain yield pooled over potassium rate and application timing for clay soils.

Nitrogen Rate (kg ha^{-1})	Plant Height† (cm)	Lodging Score† (1-5)	Lodging† %	Grain Yield† (kg ha^{-1})
112	89 A‡	1.0 A‡	0.0 A‡	9354 A‡
224	100 B	2.3 B	9.0 B	11750 B

‡ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$.

Table 4.12 Grain yield and plant height as affected by N rate and grain yield as affected by fungicide application timing {none= no fungicide applied, panicle differentiation (PD) or boot stage} for silt loam soils.

Nitrogen Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Plant Height (cm)
112	12100 A‡	99 A
224	13139 B	104 B
Fungicide Application Timing		
None	12409 A	
PD	12660 B	
Boot	12789 B	

‡ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$.

Table 4.13 Plant height as affected by the interaction of N rate and K rate pooled over fungicide application timing for clay soils.

Nitrogen Rate (kg ha^{-1})	K Rate (kg ha^{-1})	Plant Height (cm)
112	0	94 A‡
112	68	94 A
112	135	93 A
224	0	102 B
224	68	102 B
224	135	104 C

‡ Means followed by same letter for each response variable are not significantly different $P \leq 0.05$.

Literature Cited

Adair, C.R., and E.M., Cralley. 1950. 1949 rice yield and disease control tests. P. $9^{-2}0$. Arkansas Agric. Exp. Stn., Fayetteville.

Anonymous, 2012. Horizon Ag. www.horizonseed.com/clearfield-varieties. Date verified July 2, 2012

Berry, P.M., M. Sterling, and S.J. Mooney. 2006. Development of a model of lodging for barley. J. Agronomy & Crop science $192:151^{-1}58$

Bhiah, K.M., C. Guppy, P. Lockwood, and R. Jessop. 2010. Effect of potassium on rice lodging under high nitrogen nutrition. 19th World Congress for a Changing World. P. $136^{-1}39$.

Blanche, S.B., X. Sha, D.L. Harrell, D.E. Groth, K.F. Bearb, L.M. White, and S.D. Linscombe. 2011. Registration of ‘CL151’ rice. Journal of Plant Registrations, Vol. 5, No. 2, May 2011 p.$177^{-1}80$

Buehring, N. 2008. Mississippi rice growers’ guide. P. 4. Mississippi State Extension publication 2255.

Carmer, S. G., W. E. Nyquist, and W. M. Walker. 1989. Least significant differences for combined analysis of experiments with two or three-factor treatment designs. Agron. J. 81:665–672.

Cralley, E.M. 1938. Effects of fertilizer on stem rot of rice. Bull. 383. Arkansas Agric. Exp. Stn., Fayetteville.

Griggs, B.R., R.J. Norman, C.E. Wilson, and N.A. Slaton. 2007. Ammonia volatilization and nitrogen uptake for conventional and conservation tilled dry-seeded delayed-flood rice. Soil Sci. Soc. Am. J. 71:745-751.

Harrell, D.L., J.A. Bond, and J. Saichuk. 2009. Soils plant nutrition and fertilization. p. 23-34. In. J.S. Saichuk (ed.) Louisiana rice production handbook. Pub. 2321. LSU AgCenter, Baton Rouge, LA.

Harrell, D.L., B.S. Tubana, J. Lofton, and Y. Kanke. 2011. Rice response to nitrogen fertilization under stale seedbed and conventional tillage systems. Agron. J. 103:494-500.

Huber, D.M., and D.C. Arny. 1985. Interactions of potassium with plant disease. P. 467-479. In R.D. Munson (ed.) Potassium in Agriculture. ASA, CSSA, and SSSA, Madison, WI.

Jain, S.S. 1976. Studies on the effects of nitrogen, phosphorous, and potassium on stem rot of rice. ORZYA 13:55-61.

Jayaraj, J., K. Ramanujam, and R. Ramabadran. 1991. Effect of potash nutrition on the stem rot incidence and yields of rice. J. Pot. Res. 7:62-66.

Kanter, D.G., T.W. Walker, N.W. Buehring, W. L. Soloman, L.S. Lanford, S. Shaifer, P. Fitts, and J.L. Corbin. 2011. Mississippi rice variety trials. Mississippi Agriculture & Forestry Experiment Station publication.

Liebhardt, W.C. and R.D. Munson. 1976. Effect of chloride and potassium on corn lodging. Agron. J. 68:425-426.

Maschmann, E.T., N.A. Slaton, R.D. Cartwright, and R.J. Norman. 2010. Rate and timing of potassium fertilization and fungicide influence rice yield and stem rot. Agron. J. 102:163^{-1}70.

Norman, R.J., C.E. Wilson, Jr., N.A. Slaton. 2003. Soil fertilization and mineral nutrition in U.S. mechanized rice culture. P.331-411. In C. Wayne smith and Robert H. Dilday (ed.) Rice: Origin, History, Technology, and Production. John Wiley & Sons, Hoboken, New Jersey.

Sims, J.L. and G.A. Place. 1968. Growth and nutrient uptake of rice at different growth stages and nutrient levels. Agron. J. 60:692-696.

Slaton, N.A., R.D. Cartwright, and C.E. Wilson, Jr. 1995. Potassium deficiency and plant diseases observed in rice fields. Better Crops 79:12^{-1}4.

Slaton, N.A., R.D. Cartwright, J. Meng, E.E. Gbur Jr., and R.J. Norman. 2003. Sheath blight severity and rice yield as affected by nitrogen fertilizer rate, application method, and fungicide. Agron. J. 95:1489^{-1}496.

USDA-NRCS. 2013. Web soil survey. Available at http://websoil.survey.nrcs.usda.gov/app/WebSoilSurvey.aspx (verified 18 December 2013). USDA-NRCS, Washington, DC.

Usherwood, N.R. 1975. Reduce lodging with potassium. Better Crops Plant Food 46:6^{-1}1.

Walker, T.W., S.W. Martin., and P. Gerard. 2006. Grain yield and milling quality response of two rice cultivars to top-dress nitrogen application timings. Agron. J. 98:1495^{-1}500.

Walker, T.W., J.A. Bond, B.V. Ottis, P.D. Gerard, and D.L. Harrell. 2008. Hybrid rice response to nitrogen fertilization for midsouthern United States rice production. Agron. J. 100:381-386.

Walker, T.W., R.L. Atwill, J.L. Corbin, P.W. Fitts, L.S. Lanford, and S.D. Shaifer. 2013. Mississippi rice variety trials. Miss. Agric. and For. Exp. Stn. Information Bulletin No. 481. Mississippi State, MS.

Webster, R.K., and P.S. Gunnell. 1992. Compendium of rice diseases. APS Press, St. Paul, MN