5-2014

Efficacy of Rice Insecticide Seed Treatments at Selected Nitrogen Rates for Control of the Rice Water Weevil, Lissorhoptrus Oryzophilus Kuschel

Mallory Elise Everett
University of Arkansas, Fayetteville

Efficacy of Rice Insecticide Seed Treatments at Selected Nitrogen Rates for Control of the Rice Water Weevil, *Lissorhoptrus oryzophilus* Kuschel

Efficacy of Rice Insecticide Seed Treatments at Selected Nitrogen Rates for Control of the Rice Water Weevil, *Lissorhoptrus oryzophilus* Kuschel

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Entomology

by

Mallory Everett
Arkansas State University
Bachelor of Science in Agribusiness, 2012
University of Arkansas
Master of Science in Entomology, 2014

May 2014
University of Arkansas

This thesis is approved for recommendation to the Graduate Council

Dr. Gus Lorenz III
Thesis Director

Dr. Nathan Slaton
Thesis Director

Dr. Jarrod Hardke
Committee Member

Dr. Rob Wiedenmann
Committee Member

ABSTRACT

Seed-applied insecticides are the standard control method used to prevent rice water weevil (*Lissorhoptrus oryzophilus* Kuschel) injury to rice (*Oryza sativa* L.) roots, and often results in greater yields than rice that receives no seed-applied insecticide. Yield increases from seed-applied insecticides often occur even when insect pressure is low and should not cause yield loss. The research objective was to evaluate the effect of urea-nitrogen rate and seed-applied insecticide on number of rice water weevil larvae, nitrogen uptake and rice grain yield. Six trials were conducted at the Pine Tree Research Station (PTRS) and the Rice Research Extension Center (RREC) to examine the response of rice plants receiving different insecticide-seed treatments and urea-nitrogen rate combinations. Insecticide-seed treatments included label rates of clothianidin, thiamethoxam, and a no-insecticide (fungicide only) control, in combination with season-total nitrogen rates of 0, 50, 100, 150, and 200 kg urea-nitrogen/ha. Rice seed that was treated with clothianidin or thiamethoxam generally had equal numbers of rice water weevil larvae, which were significantly fewer compared to rice that received no insecticide with an equivalent urea-nitrogen rate. Nitrogen uptake at panicle differentiation was not affected by insecticide-seed treatments at four of six sites and usually increased positively and linearly as urea-nitrogen rate increased. As urea-nitrogen rate increased, grain yield increased either linearly or non-linearly. Averaged across urea-nitrogen rates, both insecticide seed treatments had similar yields that were 4 to 7% greater than the grain yields of rice that received no insecticide at four of the five harvested sites.

ACKNOWLEDGEMENTS

I would like to thank my major advisors, Dr. Gus Lorenz and Dr. Nathan Slaton, for their support, advice and encouragement throughout the course of this study. I am very appreciative of the time they have invested in me and the patience they have shown throughout my learning. Special thanks are also extended to my committee members, Dr. Jarrod Hardke and Dr. Rob Wiedenman, for their guidance and assistance during this process. I would also like to thank Syngenta and Valent U.S.A for sponsoring this study and making this research possible.

I must also mention the support provided by the Arkansas Cooperative Extension Service's Entomology lab, particularly Nicki Taillon and the summer crews. I am sincerely thankful for the long hours and hot days that they have devoted to assisting me in my research. I would also like to thank the faculty, staff and students of the University of Arkansas' Entomology Department, especially Benjamin Thrash and Derek Clarkson. Their support, friendship and entertainment has made this experience so much more enjoyable. I would also like to express my gratitude to the University of Arkansas Graduate School for all of their help in editing my thesis.

Most importantly, I would like to thank God and my family for their endless support. Special thanks to my grandmother, Lucille Everett, for uplifting me with encouraging words and supporting me in every way possible. Also, special thanks to my sister, Kaitlin Everett, for her patience and reassurance when I needed it most. I would also like to thank my father, Scott Everett, for instilling in me a passion for agriculture and the determination to be the best in all aspects of life. My sincere gratitude is extended to all those mentioned in this acknowledgement. This endeavor would not have been possible without their contributions.

TABLE OF CONTENTS

TABLE OF CONTENTS

INTRODUCTION

Rice is the principal food source for approximately 40% of the planet's population, and the demand for rice is increasing (Buresh and De Datta 1990). In 1990, 112 countries grew rice on over 145 million hectares, producing more than 500 million metric tons of grain (Chang 2000). Although rice is grown and consumed all over the world, only around 5% of all rice produced enters the world market, because the remaining 95% is produced and consumed within the boundaries of the Asian continent (Chang 2000).

Rice is mostly starch, low in fiber, and allergen free, making it a suitable component for various food, cleaning, and miscellaneous products produced and consumed worldwide .The inhabitants of eastern hemisphere countries place particular importance on rice, making it the focal point of nearly every meal. In southeastern Asia, rice can provide anywhere from 55 to 80% of the total caloric intake. Rice can also be found in processed products, such as baby food and formula, beer, wine, cereals, facial powder, and polishes (Chang 2000).

RICE IMPORTANCE IN THE U.S.

The 2007 USDA Census of Agriculture reported 6,084 farms producing rice on 1,116,444 ha (2,758,792 acres) in the U.S., averaging eight metric tons/ha (7200 lb/acre, USDA Census of Agriculture 2009). Arkansas, California, Louisiana, Mississippi, Missouri, and Texas are the United States' top rice-producing states accounting for nearly all hectares of U.S. annual rice production (USDA Census of Agriculture 2009). One-half of the annual U.S. rice crop is sold within domestic markets while the other one-half is exported to countries such as Mexico, Northeast Asia, and Central America (USDA ERS 2014). The U.S. accounts for more than 10% of annual global trade and is the only major exporter of rough rice (USDA ERS 2014).

RICE IMPORTANCE IN ARKANSAS

Arkansas is ranked number one in rice hectares planted and kilograms of grain produced and has been the number one rice-producing state in the U.S. since 1973 (Hardke and Wilson 2013a). Currently, Arkansas accounts for 48% of total U.S. rice production on 526,091 hectares (1.3 million acres) of land, averaging of 8,389 kg of rice grain/ha (166 bushels/acre; Hardke and Wilson 2013a).

RICE CULTURE IN ARKANSAS AND THE MID-SOUTH

RICE PRODUCTION CALENDAR AND PROCEDURES

Rice planting in Arkansas typically begins during the last week of March and continues until June, although 50 to 95 % of planting is completed by the end of April. Rice typically reaches the four- to five-leaf stage near the end of May or early June and is ready to receive a permanent flood. Harvest begins in mid-August and may last until the beginning of November. Rice yields have increased over the years due to new cultivars, production methods or technologies, setting the state yield record in 2012 of 8.39 metric tons/ha (7470 lb/acre). Rice yields in Arkansas range from 7 to 11 metric tons/ha (6,250 to 9,800 lbs/acre) at 12% grain moisture (Hardke and Wilson 2013a).

DRY-SEEDED PLANTING PROCEDURES

In Arkansas, 80% of rice is drill-seeded into the soil. The remaining 20% is established by broadcasting dry seed (~15%) and water seeding (5%). Before seeds are sown, the seed-bed must be free of potholes, stubble, or trash (Wilson et al. 2013). Production fields are usually left in rough form during the winter, so the previous year’s crop residue must be tilled under by disking the soil at a 5- to 10-cm depth depending on the soil texture and condition. Once the field is plowed, a landplane is used to reduce potholes or high spots within the field (Hardke and Wilson 2013a). Field cultivators may be used just prior to planting for optimal seed-bed preparation. If tilling a clay soil, a roller is often used after the rice is planted to break up clods and compact the soil to ensure seed-to-soil contact and increase stand. Tillage practices are dependent on the soil texture and condition.

Drill rows are commonly between 15 and 20 centimeters (6 and 8 inches) wide, and rice seeding rate is dependent on seed variety or hybrid cultivar. Seeding rates are adjusted for the specific cultivar, seeding date, seeding method, soil texture, and seedbed condition. However, Frizzell et al. (2006) found that a row spacing of 17.8 cm (7 in) and a seeding rate of 76 kg seed/ha (67.5 lb seed/acre) produced optimal yields in conventional rice cultivars. Rice seed should be between 1 to 3 cm deep to ensure access to soil moisture and facilitate rapid and uniform emergence. In general, levees should be present for every 6 cm drop in elevation, decreasing this interval for flat areas and increasing the interval for fields with more of a slope. A section of each levee should be pushed out, and a levee gate should be installed to assist with water management (Wilson et al. 2013). Approximately 62% of rice in Arkansas is still irrigated by this conventional levee and gate system. As of 2012, multiple-inlet irrigation, which uses poly-tubing to irrigate, was being used on 38.5% of rice production fields in order to conserve water and labor (Hardke and Wilson 2013b).

GROWTH

Germination occurs when the seed has absorbed enough water to become soft and flexible. The ideal temperature is 31°C (87°F), but germination can occur at temperatures within the range of 10 to 42°C (50 to 107°F). Once the seed has absorbed enough water to become soft, the coleorhiza breaks through the seed coat and elongates, and the radicle emerges to anchor the seed in the soil. The coleoptile continues to extend and lateral roots begin to form. Emergence occurs once the first internode, the mesocotyl, lengthens enough to push the tip of the coleoptile above the soil surface. In 15 to 25 d, the plant grows to the four-leaf stage. Tillering begins at the five-leaf stage when the first tiller emerges from the axillary bud of the second leaf on the culm and continues until the maximum tillering potential is achieved. Four to five weeks after tillering begins, a green band or "green ring" forms over the first node which signifies the beginning of panicle formation and reproductive growth. Internodes continue to elongate and a top internode space of 1.25 to 2.0 cm (0.5 to 0.75 inches) is commonly known as panicle differentiation, the time when the number of potential grains per panicle is set. The panicle increases in size and moves up the plant, causing the flag leaf sheath to swell. The plant has reached the late-boot stage once the flag leaf is completely extended outside the boot (Moldenhaur et al. 2013).

In approximately 6 d, the panicle begins exiting the boot, and anthesis begins. The hull tips open to extend the filament, anther, and stigma and allow the pollen from the anther to shed. The spikelet closes and the ovary is fertilized within six hours (Moldenhaur et al. 2013). As the starches and sugars are transported to the seed, the grain grows in weight and size and changes from green to gold in color. Leaves of the rice plant begin to senesce and the grains begin to ripen. The first stage in ripening is called the milk stage when the contents of the kernel are a soft, white liquid. The starch in the grain begins to harden during the soft dough stage and has reached complete firmness by the hard dough stage. When the grain has fallen below 20% moisture it is considered mature (Moldenhaur et al. 2013).

RICE MANAGEMENT

INPUTS

Rice production inputs include fungicides, herbicides, insecticides, and fertilizer. Considering the price and risk involved in the application and plant utilization of these products, timing and precision are critical for optimal field results. Many of these inputs are applied directly to the rice seed. However, some applications must still be applied directly to the soil or plant. With rice, it is especially important to assess any nutritional deficiencies, diseases or pest pressure present in the field before the permanent flood is applied. If present, levees may inhibit or prevent ground-based equipment from entering or moving through the field and, once the field is flooded, the water prevents many applications from having proper contact with the soil or plants. Therefore, it is imperative for rice producers to seek out management methods that can be used before the permanent flood is applied to prevent yield reduction or the total loss of the crop.

INPUTS: FUNGICIDES

In spite of advancements made in rice production, disease is still a major cause of lower yields and profits on Arkansas rice farms. Producers are now planting high-yielding cultivars that are more susceptible to disease in soils with increasingly lower fertility levels and decreasing irrigation capacity. The degree of plant resistance and favorability of the environment determines the potential virulence of disease (Wamishe et al. 2013). When planting early, in clay soils, under no-till conditions, or in fields with a history of poor seedling emergence or seedling disease, a fungicide seed treatment is recommended. Though fungicide seed treatments do not stimulate growth, increase yield or control late season diseases, they can effectively protect against seedling disease and may result in a 10 to 20% increase in stand compared to seed that does not receive a fungicide seed treatment. Consult MP154, Plant Disease Control Products Handbook, for up to date information and assistance in choosing the best fungicide seed treatment for specific needs (Wilson et al. 2013).

Most diseases that occur in rice occur late season and are controlled by foliar applications of fungicides. Even when conditions are not ideal for disease, foliar fungicide applications are still necessary. For example, in 2012, there was little rainfall and continuous high temperatures. Yet, over 46% of all Arkansas rice acres received a foliar fungicide application to manage disease (Hardke and Wilson 2013b). Rice plants can be infected with various diseases such as sheath blight, blast, stem rot, kernel smut, etc., and the type of infection it develops depends on the variety, time of planting and environmental conditions. Sheath blight is the most prominent rice disease, causing some level of damage in almost every rice field in Arkansas each year. Sheath blight is caused by a hard, brown fungus called *Rhizoctonia solani* AG1-1A that can lie dormant in the soil for several years or survive in infected crop residue for a shorter period of time. The infected area moves out of the soil and spreads by way of water or soil cultivation, eventually infecting the rice sheath during the late tillering or reproductive stages. Rice plants infected with sheath blight will have long, oval, lesions with purple outlines at early stages of infection and develop bands of dying tissue on leaf blades that will eventually form sclerotia, which fall off the leaves to continue disease activity within the field (Wamishe et al. 2013).

There are three factors that control the severity of disease: favorability of the environment, susceptibility of plants, and strength of disease. Producers can decrease or eliminate disease by taking actions to control at least one of these factors. Disease management begins at choosing what variety of rice to plant and determining what diseases it is most susceptible too. By knowing what diseases are most likely to occur, the producer can be aware of the favorable conditions that increase disease severity and when and where to scout rice plants for disease symptoms. After planting, the producer can make management decisions to provide an unfavorable environment for susceptible diseases. Maintaining a deep flood and avoiding thick stands by lowering the seeding rate or nitrogen application are common practices used to decrease disease pressure. However, the environment cannot be controlled completely and no variety is resistant to all diseases, so scouting regularly is still necessary. A foliar application of a fungicide is generally applied to control the strength of the disease and prevent yield reduction. Application recommendations and rates can be found in the MP154 (Wamishe et al. 2013).

INPUTS: HERBICIDES

Weed management is one of the leading issues in rice production. These invasive plants compete with rice for sunlight, water, and nutrients, causing reductions in yield. If weeds are left uncontrolled, their seeds will be harvested with the rice grain, reducing milling quality and grade. Some seeds are threshed and pass through the combine, increasing the weed seedbank and enhancing the probability of herbicide-resistant weeds in the future. Weeds may also increase the pressure of insects and various plant diseases (Scott et al. 2013).

Arkansas rice producers spend about $100 million each year for weed control. The Rice Research Verification Program found that producers, in the program, make, on average, two herbicide applications per year costing almost $28 per ha ($70 per acre, Scott et al. 2013). In order to effectively control weeds, producers must familiarize themselves with weed identification, the period in which certain weeds emerge and compete, history of herbicide resistance, and the amount of competition that certain weeds will present to a particular rice cultivar.

Grass weeds such as barnyardgrass (*Echinochloa* spp.), sprangletop (*Leptochloa* spp.), and broadleaf signalgrass (*Brachiaria* spp.) emerge in rice fields during early season. Barnyardgrass is the most frequent and produces biomass faster than rice, making it a tough competitor for young crops. If not monitored, barnyardgrass can reduce yield up to 70%. Thus, it is crucial for producers to control these grasses soon after their emergence before crops become overwhelmed. Most weeds will not continue to emerge once permanent flood is established because conditions are not ideal for germination. Management of these particular weeds is usually only necessary before flood (Scott et al. 2013).

Propanil, a contact herbicide, has been the most widely used rice herbicide for over 40 years. Propanil should ideally be applied when rice is at the one-to three-leaf stage when temperatures are between 24 to 32°C (75 and 90°F). Although propanil has successfully controlled weeds for 40 years, there are problems associated with its use. Propanil does not provide residual weed control, so two applications may be necessary. Also, propanil resistant weeds are becoming a common occurrence, especially in rice fields where crop rotation is less frequent. There are numerous herbicide options available for such cases of resistance. Herbicides such as Clincher and Ricestar HT control barnyardgrass that is resistant to Facet or propanil. Many producers are combining their normal contact propanil spray with a preemerge application of Command to effectively manage weeds. Other residual herbicides, such as Bolero or Prowl, are also available for weed control (Scott et al. 2013). Application rates, timings, and conditions should be assessed before the use of any product to achieve optimal performance.

Like early-season grassy weeds, broadleaf weeds will not germinate under flooded conditions and can reduce yield, milling quality, and grade if no control measure is taken. However, if allowed to emerge before flood or grow atop levees, broadleaf weeds can become an issue during midseason. Dark-seeded broadleaf weeds common in Arkansas include duck salad (*Heteranthera*), hemp sesbania (*Sesbania*), northern jointvetch, morningglory (*Aeschynomene* spp.), and smartweed (*Polygonum* spp.). Red rice, however, is the prime mid-season weed, having the potential to cause up to 82% loss in yield (Scott et al. 2013). Before the appearance of herbicide resistant rice, there was no efficient control for red rice (Davis et al. 2011). ‘Liberty Link’ rice was the first to exhibit resistance against broad-spectrum herbicides. Due to its genetically modified organism (GMO) status, however, it never succeeded on the market. The ‘Clearfield’ technology was introduced in 2002 as a mutated strand developed specifically to be resistant against imidazolinone herbicides. This new technology became the first widely accepted and adopted defense against red rice with producer adoption increasing each year (Shivrain et al. 2006). Despite its growing popularity, continuous use of this technology inevitably led to red rice resistance that was reported in 2006. Clearfield technology is still used today but often with additional control provided by exploiting the advantages associated with soybean (*Glycine max* (L.) Merr.) crop rotation. Herbicide-resistant soybeans, such as ‘Roundup Ready’ and ‘Liberty Link' varieties, allow for over-the-top herbicide applications such as glyphosate and Ignite, respectively (Davis et al. 2011). However, for resistant weeds or high broadleaf weed pressure, residual weed control from soil applied herbicides is standard. Residual herbicides such as Bolero, Command, Prowl, Newpath, and Facet can be applied as a tank mix with propanil for contact and residual control, or they can be applied directly to the soil before weed emergence for residual control. Due to the difficulty associated with post-emergence weed control and the occurrence of resistant weeds, it is recommended that pre-emerge herbicides be flushed (e.g., watered) in to make certain the herbicide is activated in a timely manner (Scott et al. 2013).

One of the most important, yet overlooked, aspects of herbicide application is rice cultivar. The level of weed threshold is largely dependent on the characteristics of the chosen rice cultivar. Rice and weeds are in competition for available resources such as water, nutrients, and sunlight. Therefore, the fastest plant to grow to the largest size will dominate the resources. Hence, a rice variety that grows tall and tillers quickly would be ideal. Short cultivars that do not tiller well are more likely to be overrun by weed pressure and experience yield declines. Once weed threshold has been met, herbicide application is necessary. There are a number of herbicides on the market that are applied in different ways, used for different pressures, priced at different amounts, and perform in different manners. Producers can choose between contact herbicides such as propanil or products with residual activity such as Bolero, Facet, or Prowl (Scott et al. 2013). Weed thresholds, cultivar information, plant size charts, herbicide ratings, and application rates can all be found in the 2013 Arkansas Rice Production Handbook or Arkansas 2014 MP44 to help best choose the appropriate herbicide control methods for the specific weed problem.

INPUTS: INSECTICIDES

Insect pests of rice may damage the plant by boring in the stem or feeding on leaves, stems, roots, panicle, or seed, and all growth stages are susceptible to some pest, from emergence to harvest. Knowledge of when pests attack, the damages they cause, and cultural practices that may reduce insect populations are essential to effectively protect crop yield. In Arkansas, only a few insects threaten rice yield and quality enough to require an insecticide application. However, insecticides are necessary to control pests when they exceed threshold and may threaten crop grain and/or milling yields. The following information will describe the major and minor pests of rice and the most effective control methods.

Grape colaspis [*Colaspis brunnea* (F.)] is an early-season pest of rice, which affects rice plants from seedling emergence to the 3-leaf growth stage. Adults are approximately 0.5 cm (0.2 inch) in length, oval shaped, and gold in color. Larvae are white grubs approximately 0.64 cm (0.25 inch) long and have a brown head. Adults will lay their eggs in corn (*Zea mays*) or soybean (*Glycine max*) fields and larvae will overwinter in the soil until spring when they move up the soil profile to feed on roots. Soybeans are a common rotational crop with rice, so grape colaspis often feed on young rice seedling roots and mesocotyl during the spring. Grape colaspis larvae girdle the underground portion of the plant until the root is a frail, threadlike structure, causing the plant to yellow, wilt, and have slow growth. Areas of grape colaspis damage are sporadic and most commonly seen in silt loam soils, though damage is occasionally observed in rice grown on soils with higher clay content. Older plants may not show these symptoms, so scouting for grape colaspis should be done during the seedling stage (Lorenz and Hardke 2013).

Since aboveground symptoms may resemble nutrient disorders, salinity or disease issues, observation of the underground injury is necessary to verify grape colaspis injury. A soil sample that is 5 to 10 cm in depth should be taken and examined for presence of the white grub larvae or feeding damage. If a history of grape colaspis is known, insecticide seed treatments such as Cruiser®5FS and NipsIt INSIDE 5FS® are recommended for early and residual defense. If no insecticide is applied to the seed, a foliar pyrethroid application of Mustang Maxx or Karate that is followed by a rain or flush irrigation is recommended. Cultural control methods are also effective in reducing grape colaspis damage. Fields can be deeply disked in the fall or spring to kill and disrupt the larval cycle. On fields that cannot be disked, such as planted fields or no-till, the field can be fertilized with nitrogen and temporarily flooded for 48 hours or flushed. The nitrogen will help seedlings recover from injury. The water will kill grape colaspis larvae and allow damaged plants to grow more roots, increase nutrient uptake, and grow to be less vulnerable to grape colaspis damage (Lorenz and Hardke 2013).

The rice water weevil [*Lissorhoptrus oryzophilus* (K.)], is the key pest in rice production, potentially affecting the rice plant from seedling to panicle emergence. Adult rice water weevils are small snout beetles that are approximately 3mm in length and grey or brown in color. Adults overwinter in leaf-litter habitats and emerge from late April to May to feed on host plants, leaving linear feeding scars that run parallel to the leaf's midvein. Though adults feed on the leaves, their feeding is usually not economically damaging. Economic damage in rice is most often associated with the larval stage of the rice water weevil. Rice water weevil larvae are white grubs and about 8mm in length. Larvae damage the rice by pruning the roots, decreasing nutrient uptake necessary for growth and yield potential. The total life cycle of the rice water weevil lasts about 35 to 40 d. Including overwintered adult rice water weevils, two and a partial generation normally affect a single growing season (Lorenz and Hardke 2013).

Sampling for rice water weevil can be done either by counting leaf scars or collecting soil core samples. Sampling for adult rice water weevil damage should take place two to seven days after permanent flood is established. Sampling requires examining the youngest mature leaf of plants at least 2 m (6 ft) from the outermost levee and sample at intervals across the field for accurate representation. If 60% or more of the examined plants have feeding scars, the threshold of larvae is considered to have been met and control methods generally are implemented. Scouting for rice water weevil larvae is done by sampling the root system and surrounding soil for a larval count and root pruning. Samples 10 cm (4 in) in diameter and 7.5 cm (3 in) are should be taken two to three weeks after the permanent flood is established. Soil cores are washed in a bucket of clean water, rinsing the roots vigorously until soil is removed from the roots and root pruning, if present, is evident. Rice water weevil larvae will float to the top of the water, and the number and size of larvae can be used to predict current and future damage (Lorenz and Hardke 2013).

The rice stink bug [*Oebalus pugnax* (F.)] feeds and causes damage to rice from panicle emergence to grain maturity. In Arkansas, at least four generations of rice stink bug occur each year. The adult is about 1.27 cm (0.5 inch) long with forward directed spines, red antennae, and a golden color resembling mature rice grain. Adult rice stink bugs will overwinter in matted grasses and litter and emerge to feed from April to May. Though host species of *Panicum* are most critical to its' population dynamics, the rice stink bug has over 40 wild hosts and several cultivated hosts including sorghum, oats, rye, wheat, and rice. Eggs are placed upon the leaves, stems, or panicles of the most suitable hosts in two parallel lines. Rice stink bug eggs are small and barrel shaped, changing from green to red before hatching. After four to seven days, the first instars hatch and remain around the egg remnants ingesting only water. The second through fifth instars feed on seeds for the duration of the nymphal stage, 15 to 28 d. The rice stink bug adults' average lifespan is around 50 d, and they will actively feed until the plant senesces or the temperatures drop.

When feeding, the rice stink bug pierces the grain with its stylet and sucks out the content, leaving a hardened salivary secretion called a 'feeding sheath' as the only evidence that feeding has occurred. Early feeding before the milk stage stops kernel development, while feeding during milk and soft dough stages will result in the removal of part or all of the seed contents, both of which cause yield loss. Pathogens introduced from rice stink bug feeding may cause discoloration, weakening, and ultimately quality reduction. Scouting for this pest should begin at 75% panicle emergence and continue weekly until grain maturity. Scouting in the morning or late evening gives the best estimates of rice stink bug densities. Thresholds for rice stink bug are five per ten sweeps at the first two weeks of heading and ten per ten sweeps at the second two weeks of heading (Lorenz and Hardke 2013). Numbers may be higher in field borders that are weedy or by wooded areas. Treating the specific area of rice stink bug concentration may be more feasible than treating the whole field with an insecticide.

Minor pests exist in rice and include but are not limited to rice stalk borers (*Chilo plejadellus*), sugarcane borer (*Diatrea saccharalis*), and fall armyworms (*Spodoptera frugiperda*). The most common of these pests, however, are chinch bugs (*Blissus leucopterus leucopterus*) and aphids (*Schizaphis graninum*, *Rhopalosiphum padi*; Lorenz and Hardke 2013).

FERTILIZATION

NITROGEN

Of all macro and micro nutrients required for rice production, nitrogen is applied more times and in larger amounts than any other nutrient (Norman et al. 2003). Nitrogen is an essential component of rice production, effecting the plant's concentration of amino acids, proteins, nucleic acids, chlorophyll, and several plant hormones necessary for plant growth and survival (Shi et al. 2010). Depending on the chosen rice cultivar, 16 to 17 kg of nitrogen is removed for every one-ton of rough rice produced, so added fertilizers are imperative to achieve a vigorous, high-yielding crop (Choudhury and Kennedy 2005). In the southern U.S., most soils used for rice production are nitrogen deficient, and nitrogen application may account for up to 25% of total variable commercial production costs (Dillon et al. 2012).

Approximately 85% of rice is produced under wetland conditions where rice absorbs NH_4^+ in the roots and shoots and transforms the ammonia into organic molecules (Choudhury and Kennedy 2005, Shi et al. 2010). Nitrogen that is absorbed during the vegetative growth stage promotes early plant growth and tiller number. Tiller number is directly correlated to the number of panicles. Therefore, by adding nitrogen, tiller and panicle number increase which increases yield potential (Mae 1997). As the rice plant grows, nitrogen helps the plant by increasing leaf size, increases the number of spikelets and increasing protein content of the grains (De Datta 1981).

Nitrogen can exist in many forms in the air, soil, water, or fertilizers, but it must be transformed to ammonium (NH_4^+) or nitrate (NO_3^-) to be taken up by the rice plant. Ammonium is taken up by the rice root system and moves through the soil mostly by diffusion. Under flooded, anaerobic conditions, NH_4^+ is stable in the soil. Nitrate, an anion, is not stable under flooded conditions. With oxygen absent, electrons bind to NO_3^- causing nitrogen to be lost in the atmosphere in the form of N_2, a nitrogen-loss mechanism known as denitrification. Therefore, NH_4^+ forming fertilizers are the most recommended for flooded soils, because NH_4^+ is the principal form of nitrogen taken up by rice in a flooded soil. However, NH^+_4 can also be lost by means of ammonia volatilization, leaching, or nitrification, with a consequential loss of $NO_{3.}$ Proper fertilizer source, rate, application timing, and management should be used to ensure successful nitrogen fertility for rice production (Norman et al. 2003).

For the last 40 years, nitrogen application rates have been determined based on the chosen rice cultivar, soil texture, and previous crop. The problem with this method is that it assumes that all soils of a certain textural class (e.g., clay or silt loams) require the same amount of nitrogen, resulting in correct fertilization of some fields and over-or under-fertilizing others. Nitrogen-Soil Test for Rice (N-STaR) was developed to more accurately assess nitrogen requirements of a particular field's soil by measuring its ability to mineralize nitrogen.

Recommended rates range from 124 to 168 kg nitrogen/ha (110 to 150 lb N/acre), and depend on the nitrogen requirements of the cultivar (Normal et al. 2013). Nitrogen for dry-seeded rice can be applied as a single preflood application or as a split application, one application before the flood and another nitrogen application during midseason. In smaller fields where the flood can be applied quickly to prevent volatilization or where urea has been treated with an effective urease inhibitor, nitrogen should be applied in total onto dry soil before flood. Split applications of nitrogen work best for larger fields that cannot be flooded in a timely manner to incorporate nitrogen without risking loss. No matter the method of application, proper management of preflood nitrogen is critical for plant growth.

The early application of nitrogen should be made onto dry soil when rice is at the four- to five-leaf stage before flooding. Ammonium-based fertilizers, such as urea, urea treated with an effective urease inhibitor, and ammonium sulfate, are recommended for early-season nitrogen applications (Norman et al. 2013). Urea is the most commonly used source due to its high nitrogen concentration and relatively low price (Dillon et al. 2012). Urea hydrolyzes into the soil, producing $(NH_4)_2CO_3$ which is only weakly absorbed by soil colloids. Losses in urea by leaching and runoff are greater when urea hydrolysis is low, so it is important for urea to be completely absorbed by the soil before permanent flood is applied (De Datta 1981). The rice field should be flooded ≤ 2 d after application for silt loams and ≤ 7 d for clay soils with at least a 5-cm deep (2 inch) flood and maintained for three weeks. Timely flooding and consistent flood maintenance incorporates the nitrogen into the soil and reduces the probability of nitrogen loss (Norman et al. 2013). Even when the flood is applied in a timely fashion, however, only a portion of the urea is expected to be utilized by the plant. Much of the applied nitrogen can be lost by ammonia volatilization, denitrification, leaching, or runoff (Choudhury and Kennedy 2005). However, while water is the catalyst for nitrogen utilization in rice plants, standing water is also the haven for the crops' ubiquitous and most damaging pest, the rice water weevil.

CHAPTER ONE

LITERATURE REVIEW

INTRODUCTION

Lissorhoptrus oryzophilus Kuschel, commonly known as the rice water weevil, has been associated with rice ever since the seventeenth century when rice began being produced as a crop (Thompson et al. 1994). Since then, the rice water weevil has maintained the status of being the most ubiquitous and injurious pest in all of rice production worldwide (Saito et al. 2005). Yield losses of 10 to 33% are a common occurrence predominantly due to the damages caused by larval feeding (Way and Bowling 1991). Therefore, it is important for rice producers to acquaint themselves with the biology, life cycle, and damage potential of this pest, and participate in effective pest management practices to prevent significant damage or severe yield loss.

BIOLOGY

Adult rice water weevils are approximately 3mm in length, grey or brown in color with dark spots on the dorsum and have a distinctive weevil snout. They spend winters in dense foliage such as Spanish moss, tangled grasses, rice stubble, or any other leaf-litter habitat (Pathak and Khan 1994). Once spring arrives and temperatures warm, rice water weevils regenerate their flight muscles and emerge from their overwintering habitat, generally from April to May. Rice water weevil adults fly from wooded areas in the night and early morning to feed on host plants such as broadleaf signalgrass (*Urochloa platyphylla*), yellow nutsedge (*Cyperus esculentus*), amazon sprangletop (*Leptochloa panicoides*), alligator weed (*Alternanthera Forssk.*), *Amaranthus* spp., eclipta (*Eclipta prostrata*), duck salad (*Heteranthera limosa*), coffee bean

(*Sesbania herbacea*), and others (Tindall and Stout 2003, Lorenz and Hardke 2013). Adults will feed on water grasses and sedges on the edge of rice fields and begin feeding on the rice plant as early as emergence and continuing to internode elongation (Tindall and Stout 2003, Lorenz and Hardke 2013). Rice water weevil adults chew longitudinally down the leaf causing long, white scarring parallel with the leaf's mid-vein. The intensity of scarring will increase as the depth of water and sparseness of stand increase. Flight muscles will degenerate in approximately one week, leaving the adults to feed and copulate. The adult feeding damage is the first indicator of rice water weevil presence and the level of pressure, but adult feeding will usually not result in loss of yield (Lorenz and Hardke 2013). Once larvae are present in the field, true damage and the opportunity for yield loss arise.

Adult rice water weevils copulate and oviposit one to two weeks after evacuation of the overwintering location and only when the plant is submerged in water (Lorenz and Hardke 2013). The female will crawl down the rice stem and insert her ovipositor through the rice sheath just below the water's surface. Rice water weevil eggs are roughly 0.8mm in size, pearly-white, and cylindrical in shape. Females lay eggs vertically within the rice sheath, and they lay two to four eggs per day. Eggs hatch about 6 to 10 d later, and the larval stage begins (Saito et al. 2005). Rice water weevil larvae are white grubs, about 8mm in length, with distinct dorsal hooks which that are used for locomotion and as modified spiracles (Isely and Schwardt 1934). After hatching, larvae immediately begin feeding on the sheath. They will eventually chew through the sheath, sink to the soil, burrow in the mud, and arrive at their true feeding site, the rice root system. Small larvae will often feed inside larger roots, killing the entire root, while larger larvae feed on the outside of the root (Lorenz and Hardke 2013). Rice water weevil larvae use their dorsal hooks as spiracles to obtain oxygen from submerged roots and feed there for the duration of the larval stage, approximately four weeks (Isely and Schwardt 1930; Lorenz and Hardke 2013). The larvae then pupate inside a watertight cocoon that is covered with soil and attached to the roots. Pupation lasts for seven to ten days and the adult stage begins. The first generation of adults feed on rice leaves from June to September and then seek out an overwintering habitat to enter diapause and hibernate. The total life cycle of the rice water weevil, from egg to adult, lasts about 35 to 40 d, and two generations plus a partial generation will be able to infest rice fields within one season (Lorenz and Hardke 2013).

Although adult rice water weevils pose no economic detriment to the rice plant, rice water weevil larvae can greatly impact the survival, vigor and yield of the rice crop. Rice water weevil larvae prune the roots when feeding, decreasing the plant's ability to absorb nutrients needed for growth. If roots are severely damaged, the plant may demonstrate signs of nutrient deficiency such as yellowing, stunting of growth, and slowed development (Lorenz and Hardke 2013). Root pruning may also cause the rice plant to lose anchoring in the soil, become completely dislodged, and float to the water's surface (Saito et al. 2005). However, rice plants usually survive, despite root pruning, by reproducing more roots once feeding subsides. Therefore, the rice is able to produce grain but with reduced yields due to the larval damage.

RICE WATER WEEVIL MANAGEMENT

SAMPLING

Sampling for rice water weevil can be done either by counting leaf scars or collecting soil core samples. Scar counts are an accurate representation of the presence and pressure of adult rice water weevils in the area. Sampling for adult rice water weevil damage should take place two to seven days after permanent flood is established. The youngest mature leaf of plants at least 2 m (6 ft) from the outermost levee should be examined for scars, and scar counts should be taken at intervals across the field for accurate representation. If no scarring is present, scouting should be done again in 4 to 5 d. If 60% or more of the examined plants have feeding scars, the threshold of larvae is considered to have been met and control methods should be implemented. Soil cores are the best way to scout for rice water weevil damage potential by sampling the root system and surrounding soil for a larval count and root pruning. A sample 10 cm (4 in) in diameter and 7.5 cm (3 in) in depth should be taken two to three weeks after the permanent flood is established. If in a field setting, place the soil core in a bucket of clean water and wash the roots vigorously in an up and down or swirling motion until soil is removed from the roots; larvae will float to the top to be counted. Once roots are rinsed completely, root pruning, if present, will be evident. The number and size of larvae can be used to predict current and future damage (Lorenz and Hardke 2013).

CULTURAL CONTROL

The first means of control for the rice water weevil was to remove water from the rice field and dry the soil, also known as “drain and dry” (Webb 1920). This method was the only means of control for 75 years and was used in Arkansas up until the late 1970s (Gifford et al. 1975, Morgan et al 1989). The early recommendation was to drain the field two to three weeks after flood establishment and to have the field remain drained for two weeks. This window of time was chosen to cause death of the larvae without seriously injuring the rice crop (Webb 1920). This method proved to be effective in experiments conducted in 1931 where 75% of larvae died as a result of water drainage (Isely and Schwardt 1932). However, there are issues and risks associated with draining and drying rice fields.

In order for the “drain and dry” control method to be effective, the soil must dry completely, until it begins to crack, to deplete the existing rice water weevil larval population (Lorenz and Hardke 2013). Aside from the costs associated with draining and pumping water off and back onto fields, draining and drying the field may increase weed pressure, increase nitrogen loss, and cause stress to the plants due to the absence of water during critical growth period (Thompson et al 1994). This practice is used in organic production or if insecticides cannot be used and the larval density is yield threatening (Lorenz and Hardke 2013). The risks and issues involved with this practice were apparent even when it was the only means of control (Isely and Schwardt 1932). Producers and agriculturalists alike soon sought a control measure that was less risky, yet offered reasonable control at a feasible price.

CHEMICAL CONTROL: FOLIAR INSECTICIDES

Whitehead (1954) demonstrated the first insecticide control for rice water weevil larvae. Organochlorines such as aldrin, dieldrin, heptachlor, DDT, and chlordane, were sprayed on the soil surface before permanent flood establishment to effectively control larval infestations. Carbofuran (Furadan® 4 F, FMC Corporation) replaced organochlorides in 1970 as the leading resource for rice water weevil control (Thompson et al. 1994). Applications of carbofuran were made directly to the soil, preflood, and offered protection for up to four weeks after flood. After the four week margin of protection, however, fields could become re-infested and exhibit detrimental effects from feeding for over eight weeks postflood (Gifford et al. 1975). Second applications became necessary to actively control rice water weevil pressure, resulting in a less than ideal insecticide budget. Even with repeated applications, however, carbofuran worked as a better alternative than previously used methods. In spite of its popularity, the United States

Environmental Protection Agency (USEPA) outlawed granular carbofuran in 1995, leaving producers in search of an alternate source of control for the rice water weevil (Saito et al. 2005).

Foliar and seed treatment options such as lambda-cyhalothrin (Karate Zeon®, Syngenta), fipronil (ICON®, Rhone-Poulenc Ag Company), and diflubenzuron (Dimilin®, Chemtura AgroSolutions) were labeled to replace carbofuran and proved to be even more effective in controlling the rice water weevil than carbofuran (Stout et al. 2000). Lambda-cyhalothrin was applied aerially as a liquid right after permanent flood establishment to deplete adult numbers before they oviposit (Way 2002). Diflubenzuron was also applied aerially as a liquid but did not have any effect on larvae or adults. Instead, it worked in controlling rice water weevil numbers by reducing the viability of eggs during early development, either within the female or oviposited in the plant (Smith et al. 1985). Fipronil was labeled as a seed treatment, targeting the rice water weevil larvae and working as a preventative treatment as opposed to previous control measures (Way 2002). Since foliar treatments have no way of penetrating through the water and into the soil where larvae feed, they can only be efficiently utilized as a control for the adult rice water weevil. Foliar applications should be made when adults are present but before they have oviposited so the present generation can be eliminated before a new one is developing. Declare, Karate Z, Mustang Max, Proaxis and Prolex are all synthetic pyrethords and are labeled for control of adult rice water weevils. Recommended rates and application times for these pyrethroids can be found in the Insect Management in Rice chapter of the MP192, Arkansas Rice Production Handbook (Lorenz and Hardke 2013). An application of a pyrethroid within10 d after flooding will target peak egg laying and usually result in adequate control. However, timing foliar treatments correctly is difficult, and pyrhethroids have a short residual period, so a second treatment may be necessary (Lorenz and Hardke 2013). Even then, rice water weevils may reinfest fields and reproduce beyond a safe threshold. The uncertainty, repeated applications, high costs, and short control period have compelled many producers to select seed treatments for residual, more efficient control of the rice water weevil larvae.

CHEMICAL CONTROL: INSECTICIDE SEED TREATMENTS

Interest in controlling rice water weevil larvae by way of an insecticide seed treatment dates back to when organochlorides were still in use. In 1954, Bowling (1957) used various wettable powder insecticides and water to form a suspension and successfully treated rice seed with insecticide. Aldrin, lindane, and deildrin provided 90% or better control of rice water weevil larvae. Along with increased control, Bowling (1957) revealed several other advantages of using insecticide seed treatments rather than foliar treatments, such as lower cost, no narrow window for application, one application for both fungicide and insecticide treatment, and protection against insects during seed storage. Since the early days of experimentation, insecticide seed treatments have maintained these advantageous results and are now the most widely adopted method used in controlling the rice water weevil (Lorenz et al. 2012).

Since the 1940s, the insecticide seed treatment market had been largely dominated by organophosphates, pyrethroids, and carbamates (Brandl 2001, Elbert et al. 2008), however, these chemistries became heavily regulated. In the early 1990s, Bayer CropScience (Leverkusen, Germany) discovered a new class of chemistry that would drastically change insecticide control, the neonicotinoids. Imidacloprid, the first neonicotinoid insecticide, was released in 1991. The small market for inseciticide seed treatments that existed in 1990 tripled in size with the introduction of neonicotinoid insecticides, which made up 77% of the market by 2005 (Elbert et al. 2008).

Elbert (2008) provided a review of the applied aspects of neonicotinoid uses in crop protection, which is summarized in the following paragraph: Neonicotinoids are applied to the seed and distributed acropetally from the roots, protecting the plant from herbivory throughout all existing and developing plant growth. These systemic properties have made neonicotinoids the most effective class of control for aphids, leaf and planthoppers, thrips, various Coleopteran species, some Lepidoptera, and even offer effective control for animal parasites and urban pests such as cockroaches and houseflies. All neonicotinoid insecticides work as agonists on the insect's nicotinic acetylcholine receptor (nAChR). This unique form of insect control allowed neonicotinoids to control pests that were resistant to preceding insecticides, and since the nAChR in insects and mammals is different, neonicotinoids allowed for a more safe and selective insect control. Neonicotinoids are used as insecticide seed treatments for cotton (*Gossypium hirsutum*), corn (*Zea mays*), soybeans (*Glycine max*), rice (*Oryza sativa*), and other crops, for which they offer broad spectrum control and residual activity compared to previous insecticide alternatives. Applying the insecticide directly to the seed allows for more accurate insecticide application and insect control beginning at planting. Previous control methods of in-furrow or total field foliar applications were quickly replaced by seed treatments, which are not only better for the environment, but also drastically reduce exposure to the producer (Elbert et al. 2008).

Imidacloprid was launched in 1991 by Bayer CropScience and gained registration in more than 120 countries under trade names such as Confidor, Admire, and Gaucho, making it the largest-selling insecticide in the world. However, in 2006, Imidacloprid's patent expired and many companies began making their own products using the neonicotinoid chemistry. In 1998, Syngenta marketed thiamethoxam (Cruiser 5FS®) as its own version of neonicotinoid insecticide seed treatment, and it became the second-largest insecticide sold. Clothianidin was launched in

2002 as a joint development between Bayer CropScience and SumitomoChemical Company (Tokyo, Japan). Poncho was the first trade name insecticide seed treatment using clothianidin, and was used to control a broad spectrum of pests in rice, cereals, corn, vegetables, etc. (Elbert et al. 2008). Valent U.S.A, the American headquarters for Sumitomo Chemical Company, released NipsIt INSIDE in 2012, as the newest insecticide seed treatment using clothianidin.

Since the release of neonicotinoid seed treatments, many studies have been done proving their efficacy of insect control, particularly in rice. The University of Arkansas has carried out studies from 2008 to 2013 to test the performance of neonicotinoid insecticide seed treatments such as Cruiser®5FS and NipsIt INSIDE 5FS®. Studies have shown that rice treated with a neonicotinoid seed treatment often results in increased stand counts, plant heights, and yields, while significantly decreasing rice water weevil larval densities when compared to rice seed receiving no insecticide seed treatment (Wilf et al 2009; Wilf et al. 2010; Taillon et al. 2013). Larger numbers of rice water weevil larvae are usually present in rice with thinner stands, resulting in increased damage (Lorenz and Hardke 2013) This suggests that early-season nitrogen management may influence the attractiveness of the rice plant to adult rice water weevils. Protecting the rice root system from insect damage may also result in improved soil and fertilizer nutrient uptake, as seen in Bt corn hybrids and the corn rootworm (*Diabrotica* spp.; Bender et al. 2013, Haegele and Below 2013). Although research has been done concerning the interaction of stand density and insecticide seed treatments (Fortner et al. 2011) and the interaction of nitrogen with fipronil (Way et al. 2006), there is currently no research investigating the interaction between nitrogen uptake and neonicotinoid insecticide seed treatments.

The primary research objective of this study was to evaluate the effect of nitrogen rate and seed-applied insecticide on the number of rice water weevil larvae, nitrogen uptake, and rice grain yield.

CHAPTER 2

INTRODUCTION

The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, has long been considered as the most ubiquitous and injurious pest to rice (*Oryza sativa* L.) in the world (Isely and Schwardt 1932, Saito et al. 2005). Adult rice water weevil feeding creates longitudinal scars where the leaf surface has been removed (Saito et al. 2005), but adult feeding does not reduce yield. Yield losses of 10 to 33% are a common occurrence due to rice water weevil larval feeding damage (Way and Bowling 1991). Rice water weevil larvae prune the root system, which compromises the root system's functions of supporting the aboveground portion of the plant, anchoring the plant to the soil, and absorbing water and nutrients.

Rice water weevil control measures available to farmers have changed over time and included the drain and dry cultural method (Webb 1920), carbofuran (Furadan® 4 F, FMC Corporation, Gifford et al. 1975), foliar application of various insecticides (Stout et al. 2000), and seed application of insecticide (Wilf et al. 2009). The use of seed-applied insecticide to control insect pests dates back to Bowling (1957), who mixed various wettable powder insecticides with water to form a suspension and applied it to seed. Bowling (1957) reported that organochlorides applied to rice seed resulted in ≥90% control of rice water weevil larvae and demonstrated insecticide seed treatment advantages compared with foliar treatments, which included lower cost, no narrow window for application, one application for both fungicide and insecticide treatment, and protection against insects during seed storage. Insecticide seed treatments have maintained these advantages and are now the most widely adopted method used for control of the rice water weevil (Lorenz et al. 2012).

Research evaluating the effect of seed-applied insecticide on rice water weevil control and rice yield has routinely shown a yield benefit from chlorantraniliprole (Dermacor® X-100, DuPont), thiamethoxam (Cruiser 5FS®, Syngenta), and clothianidin (NipsIt INSIDE 5FS® Valent U.S.A), even in field situations where rice water weevil larvae pressure was low (Plummer et al. 2012). Plummer et al. (2012) summarized field research from 2009 to 2011 and showed that the yield benefit of seed-applied insecticide (compared with no insecticide) averaged 354 kg rice grain/ha across 30 trials in the Arkansas. The reason for the consistent yield increase is presumably from reduced rice water weevil and, in some fields, grape colaspis (*Colaspis brunnea* (F.)) larva injury to seedling rice. Another possibility for the higher yields is a stimulatory effect of the insecticide on plant vigor, which was observed by Rolston and Rouse (1960) for rice treated with aldrin. The damage from rice water weevil larval feeding that results in yield loss is presumed to be largely from reduced tillering, reduced nutrient uptake, or both (Way et al 2006). However, research examining specific reasons for the rice yield loss from larval damage or yield increase from seed-applied insecticides has not been conducted, but is warranted to provide a better understanding of the response.

Seed-applied insecticides and prudent nitrogen fertilization practices can increase the vigor, growth, and yield of rice (De Datta 1981, Wilf et al. 2009). Modern rice cultivars generally require 130 to 150 kg nitrogen/ha when grown on silt loam soils and rate recommendations have not changed substantially over the last three decades (Norman et al. 2013). Research has documented that nitrogen fertilizer management can influence disease incidence and severity (Slaton et al. 2003; 2004); however, the interaction between nitrogen management and insecticide seed treatment utilization for insect control and rice growth and yield parameters has not been thoroughly investigated. Bowling (1963) concluded that increasing nitrogen rates increased rice water weevil larval abundance and rice grain yield. However, yield loss caused by the rice water weevil larvae was not different among nitrogen rates, suggesting that increased nitrogen availability did not increase rice tolerance to rice water weevil larval damage. In 2006, Way et al. (2006) reported the effects of fipronil insecticide and nitrogen rate on rice water weevil larval damage and rice yield, and showed that fipronil decreased rice water weevil larval abundance, whereas increasing the nitrogen rate increased larval density (Way et al. 2006). The tendency for rice water weevil adults to oviposit in areas with low plant density (Thompson and Quisenberry 1995) suggests that early-season nitrogen management might influence the level of attraction adult rice water weevils have to a particular field, and the magnitude of benefit from seed-applied insecticide. Protecting the rice root system from insect damage may also result in improved soil and fertilizer nutrient uptake. Corn (*Zea mays* L.) hybrids with the Bt trait imparting resistance to corn rootworm (*Diabrotica* spp.) have been shown to have greater nutrient uptake and nitrogen use efficiency in some environments than their isogenic non-Bt hybrids (Bender et al. 2013; Haegele and Below 2013).

The primary research objective was to evaluate the effect of urea-nitrogen rate and seed-applied insecticide on the number of rice water weevil larvae, nitrogen uptake, and rice grain yield. The hypotheses of this study are that: i) rice yield will increase as urea- nitrogen rate increases until the optimal rate is applied and yield will plateau when greater urea-nitrogen rates are applied; ii) rice nitrogen uptake will increase as urea-nitrogen rate increases; iii) the nitrogen uptake and grain yield of rice receiving seed-applied insecticide will be greater and numbers of rice water weevil larvae will be less than those of rice receiving no insecticide; and iv) numbers of rice water weevil larvae will increase and then reach a plateau as rice growth increases from increased nitrogen uptake.

MATERIALS AND METHODS

SITE DESCRIPTION

Six field experiments were conducted during 2012 and 2013 to determine the interaction between urea-nitrogen rate and seed-applied insecticide on the number of rice water weevil larvae, nitrogen uptake, and rice grain yield. Field studies were established at the Pine Tree Research Station (PTRS), near Colt, AR, and the Rice Research and Extension Center (RREC), near Stuttgart, AR. The trials will be referred to by the site (PTRS or RREC), year (2012 or 2013), and letter (a or b) as listed in Table 2.1. Trials PTRS-12a and PTRS-13a were planted in soil mapped as a Calhoun silt loam (fine-silty, mixed, active, thermic Typic Glossaqualfs) and followed grain sorghum (*Sorghum bicolor* L.) and soybean [*Glycine max (*L.) Merr.] respectively. Trials PTRS-12b and PTRS-13b were planted in soil mapped as a Calloway silt loam (fine-silty, mixed, active, thermic Aquic Fraglossudalfs) where soybean had been grown the previous year. The RREC-13a and RREC-13b trials were on a Dewitt silt loam soil (fine, smectitic, thermic Typic Albaqualfs) following soybean. The soil chemical property means from composite soil samples (0-10-cm soil depth) collected before planting at each of the six sites included ranges of 6.5 to 7.3 for soil pH, 1.9 to 2.5% soil organic matter, 16 to 30 ppm for Mehlich-3 extractable phosphorus, and 70 to 104 ppm for Mehlich-3 extractable potassium. Nutrients other than nitrogen were applied based on soil-test results or rates of 67 kg P_2O_5, 67 kg K_2O and 11 kg zinc/ha were applied to maintain the existing soil fertility.

TREATMENTS

Each of the six experiments was designed as a randomized complete block with four blocks and a three (insecticide-seed treatments) by five (total-urea-nitrogen rates) factorial treatment structure. Insecticide seed treatments included label rates of clothianidin [1.25 mL/kg (1.92 oz/cwt) NipsIt INSIDE 5FS®] and thiamethoxam [4.06 mL/kg (7 oz/cwt) Cruiser 5FS®] compared to seed that received no insecticide. 'Clearfield 152' (CL152) rice seed was used for all trials and was also treated with 0.238 mL/kg (0.365 oz/cwt) mefenoxam (Apron), 0.03 mL/kg (0.046 oz/cwt) fludioxonil and metalxyl-m (Maxim), and 0.652 mL/kg (1 oz/cwt) azoxystrobin (Dynasty). Seed was drill-seeded into conventionally-tilled seedbeds at a rate of 67 kg seed/ha (60 lb seed/acre) in March or April at each location (Table 2.1). Individual plots were 4.6-m (15-ft) long and contained nine rows of rice spaced 17.8-cm (7.0 inches) apart. The outside rows and the end of each plot were separated from the adjacent plots by a 76-cm (2.5-ft) wide, plant-free border. At each site the research area was surrounded by a single levee. The nitrogen-fertilizer treatments included season-total nitrogen rates of 0, 50, 100, 150, and 200 kg urea-nitrogen/ha (0, 45, 90, 135, and 180 lb urea-nitrogen/acre), which were applied in one or two applications, depending on the urea-nitrogen rate. The 0, 50 and 100 kg urea-nitrogen/ha (45 and 90 lb urea-nitrogen/acre) rates were applied in a single application at the four- to five-leaf stage. The 150 and 200 kg urea-nitrogen/ha (135 and 180 lb urea-nitrogen/acre) rates were applied in two applications with the total-urea-nitrogen rate applied as a preflood application of 100 and 150 kg urea-nitrogen/ha (90 and 135 lb urea-nitrogen/acre), respectively, followed by an additional 50 kg urea-nitrogen/ha (45 lb urea-nitrogen/acre) broadcast into the water at panicle differentiation. The preflood urea-nitrogen was applied to a dry soil surface and a 5-to 10-cm (2- to 4-inch) deep permanent flood was established within 2 d and maintained until physiological maturity as recommended for efficient nitrogen-fertilizer uptake (Norman et al. 2013). Except for the urea-nitrogen rate and seed-applied insecticide treatments, the rice in each experiment was managed for high yield closely following the guidelines described by Hardke and Wilson (2013a) for the direct-seed, delayed-flood rice production system common to the Mid-South USA (Appendix 2.1).

MEASUREMENTS

Plant density and height were measured when rice had reached the two and three-leaf stages to estimate stand density (plants per row ft) and seedling vigor. Stand counts were taken from a 3-m (10 ft) section of a single inner row of each test. Plant height was measured on five randomly selected seedlings located within one of the seven interior rows in each plot. Height was measured from the soil surface to the outstretched tip of the most recently mature leaf (Y-leaf). To measure adult rice water weevil pressure, the Y-leaf was examined from five rice plants selected at random from an interior rice row of each plot 21 d after flooding, and the numbers of scars on each leaf were counted and averaged. Leaf scarring was measured only at PTRS-12a because very little leaf scarring was observed in the other trials.

Rice water weevil larval density was evaluated by taking three soil core samples from each plot 21 d after flooding. Each soil core was taken with a 10-cm (4-inch) diameter sampler, placed in a labeled sealable bag, stored on ice, and transported to the entomology laboratory in Lonoke, AR. All soil cores were washed over a 40-mesh sieve to remove larvae and soil from the rice roots. The sieve was then immersed in salt water, causing the larvae to float to the top for counting. Larval numbers were calculated by averaging the numbers of larvae collected from the three cores in each plot.

Plant samples were taken to measure aboveground dry matter and nitrogen uptake at the early heading stage. Early heading is the growth stage at which rice maximal nitrogen accumulation during the season occurs (Guindo et al. 1994). Rice plants were cut 2.5-cm (1-

inch) above the soil surface from a 0.9-m (3-ft) section of an interior row in each plot, placed in a paper bag, oven-dried to a constant moisture, weighed for dry matter, ground to pass a 1-mm sieve, and a subsample was analyzed for nitrogen concentration by combustion (Elementar rapid N III, Mount Laurel, NJ). Total nitrogen uptake was calculated as the product of dry matter and whole-rice plant nitrogen concentration. Grain from each plot was harvested with small-plot combine, grain weights and moisture were recorded, and rough rice grain yield was calculated and adjusted to 12% moisture for statistical analysis. Grain yield at PTRS-12b was measured, but will not be included due to high variation resulting from extensive feral hog damage between plant sample collection at early heading and physiological maturity.

STATISTICS

Each experiment was a randomized complete block having four blocks and a three by five factorial arrangement of seed-applied insecticide treatments and urea-nitrogen rates. Seedling density and height measurements were taken before the urea-nitrogen fertilizer treatments were implemented, and data were analyzed as a randomized complete block with a split-plot design where site-year was the whole-plot factor (fixed effect) and the three seed-applied insecticide treatments (fixed effect), averaged across all urea-nitrogen rates, was the subplot factor. When appropriate, means were separated using Fisher's least significant difference method and interpreted as significant when $P \leq 0.05$.

For larval density, nitrogen uptake, and grain yield, replicate data were regressed across total-urea-nitrogen rate allowing for linear and quadratic model terms that depended on seed-applied insecticide treatment, site-year, and their interaction. Adult rice water weevil leaf scars were also regressed across urea-nitrogen rate (preflood) but depended on seed-applied insecticide since the measurements were taken only at PTRS-12a. The model was then simplified by sequentially omitting the most complex model term that had a *P*-value >0.10 until the final model was derived. The initial analysis for larval numbers and aboveground nitrogen uptake by rice showed that each site-year and seed treatment combination had unique intercept, linear, and quadratic coefficients. Therefore, to simplify the presentation and discussion, the regression analysis was performed by site-year allowing for the linear and quadratic terms to depend only on insecticide-seed treatment. The numbers of larvae and leaf scar counts were evaluated before the panicle-differentiation nitrogen was applied to the 150 and 200 kg urea-nitrogen/ha (135 and 180 lb total-urea-nitrogen/acre) rates. Therefore, larval regression analysis was performed across four preflood-nitrogen rates, including 0, 50, 100, and 150 kg urea-nitrogen/ha (0, 45, 90, and 135 lb urea-nitrogen/acre). The Student's residual statistics were reviewed to identify outlying data points (>±3.0), which, if present, were identified, removed, and the model was refit. When needed, differences among the predictions were determined using single-degree-of-freedom contrasts. Least-squares means were used to compare the yield, nitrogen uptake, or larval numbers across the range of applied urea-nitrogen rates.

RESULTS AND DISCUSSION

STAND DENSITY AND PLANT HEIGHT

Stand density at the two-leaf stage was affected only by the main effects of trial and seed-applied insecticide treatment (Table 2.2). Differences among the six trials were expected since each trial represents different environmental conditions (seeding date, soil temperature, and moisture, data not shown). Averaged across trials, seed treated with thiamethoxam or clothianidin emerged to denser stands that were 9.6% greater than seed that received no insecticide (Table 2.3). At the three-leaf stage, the interaction between seed-applied insecticide and trial was significant (Table 2.2). The most important component of the significant interaction is comparing how the seed-applied insecticide treatments behaved within each trial (Table 2.3). Stand density was not different among seed-applied insecticide treatments at PTRS-13a, PTRS-13b, and RREC-13a. At PTRS-12a and RREC-13b stand density was lowest for seed that received no insecticide, intermediate for seed treated with clothianidin, and greatest for seed treated with thiamethoxam. At PTRS-12b, stand density was again lowest for rice that received no insecticide, intermediate for thiamethoxam-treated seed and greatest for seed treated with clothianidin. Although the effect of seed-applied insecticide varied among trials, the final stand density was numerically and sometimes statistically greater when thiamethoxam or clothianidin was applied to seed in three of the six trials. Stand density means at both the two- and three-leaf stages exceeded the minimum recommended density for conventional (e.g., non-hybrid) varieties (107 seedlings per m^2 or 10 seedlings per ft^2; Wilson et al. 2013).

Plant height was not affected by the seed-applied insecticide by trial interaction at either the two- or three-leaf stage (Table 2.2). At the two-leaf stage, within 1 to 13 days after the emergence date (Table 2.1), seedling height was not different among seed-applied insecticides (Table 2.4), but differed among trials (Table 2.5), which was most likely due to differences in the number of days after emergence that measurements were recorded. Differences among trials were also measured at the three-leaf stage and were expected because measurements were taken at different times following emergence and each trial represented a different growth environment. By the three-leaf stage, there was a numerical seedling height advantage for thiamethoxam- and clothianidin-treated seed, but only seedlings from thiamethoxam-treated seed were statistically taller than rice seedlings that received no insecticide (Table 2.4). Wilf et al. (2009) reported that rice receiving seed-applied insecticide always had numerically greater stand densities that were sometimes statistically different than the rice that received no insecticide, and all rice receiving seed-applied insecticide had significantly greater plant height than the seedlings that received no seed-applied insecticide. Wilf et al. (2009) also found that thiamethoxam-treated seed had greater height than chlorantraniliprole -treated seed and seed that received no insecticide, which is similar to what was found in this study.

RICE WATER WEEVIL

Adult rice water weevil scars on the rice Y-leaf three weeks after flooding were counted only at PTRS-12a. The number of leaf scars decreased nonlinearly (*P*-values of linear and quadratic terms <0.0001) at a uniform rate among seed-applied insecticides, which had different intercepts ($P < 0.0001$). All seed-applied insecticide treatments shared common linear (-0.0734 ± 0.0097) and quadratic coefficients (0.00029 ± 0.00972), but the intercepts for thiamethoxam- (5.3 ± 0.5) and clothianidin- treated rice (5.4 ± 0.5) were similar and lower than that for seed receiving no insecticide (6.2 ± 0.5). Although the stand density was adequate in all treatments, the density of the canopy visually (i.e., not measured) increased as urea-nitrogen rate increased, which provided greater leaf surface area for the adult weevils to feed on. The relationship for this lone site, which also had the greatest rice water weevil larva number (Fig. 2.1), suggests that adult weevils are attracted to rice fields or field areas with less-dense canopies. There have been many studies that have supported this claim that thin stands and open water attract adult rice water weevils. Stout et al. (2002) compared flooded rice plants to rice plants that did not receive a flood and reported that adult rice water weevils fed and oviposited more on the flooded plants. Mazzanti et al. (2012) compared a hybrid rice cultivar, which is planted at low seeding rates, to a conventional rice cultivar. The hybrid rice had lower stand counts than the conventional variety and also experienced significantly higher rice water weevil larval densities (Mazzanti et al.

2012). This research also agrees with Lorenz and Hardke (2013) who state that adult rice water weevils are attracted to open water.

The initial regression analysis of the average number of rice water weevil larvae per core that allowed the linear and quadratic terms to depend on seed-applied insecticide and trial was complex showing that each seed-applied insecticide by trial combination had unique intercept, linear, and quadratic coefficients and justified performing the analysis separately for each trial (Table 2.6). The information of greatest importance is comparing the effect of the seed-applied insecticides across urea-nitrogen rates rather than comparing values among experiments. The average number of rice water weevil larvae per core in the no-insecticide control ranged from a low of 2.3 larvae per core at RREC-13b (0 kg urea-nitrogen/ha) to a high of 23.6 larvae per core at PTRS-12a (50 kg urea-nitrogen/ha, Fig 2.1). Research indicates that rice water weevil larvae damage commonly decreases rice grain yield by over 10%, and has the potential to cause up to 70% yield reduction (Stout et al. 2000). Research in Texas conducted from 2002 to 2007 with the variety Cocodrie revealed that a yield loss of 1% can be expected for every rice water weevil larva per core (Way and Espino 2012).

By applying the data of Way and Espino (2012) to current market prices and production costs, an economic threshold can be calculated for the rice water weevil. In 2014, market price for rice was approximately \$0.34 per kg (\$7 per bushel). Arkansas state average rice yield is generally around 8338 kg/ha (165 bu/acre; Hardke and Wilson 2013b). Insecticide seed treatments, on average, cost \$37.07 per ha (\$15 per acre) and usually reduce rice water weevil larval infestations by over 75% (Plummer et al. 2012). However, since insecticide seed treatments do not offer 100% control and each larva causes a 1% reduction in yield, the economic threshold must be set at a larval density low enough to protect the producer’s profit regardless. If a yield loss of 1% is expected for every rice water weevil larva per core, each rice water weevil larva will result in a loss of 83.4 kg/ha (1.65 bu/acre) or $28.36/ha loss in profit. Therefore, the threshold for rice water weevil larval density is considered to be 3 to 5 rice water weevil larvae per core.

Regression analysis performed separately for each trial showed the average number of rice water weevil larvae per core was affected by seed-applied insecticide treatment in each experiment (Table 2.6). At all sites and across all urea-nitrogen rates, rice that received no insecticide resulted in higher numerical rice water weevil larval densities than rice treated with either clothianidin or thiamethoxam. For all six sites the general numerical relationship between the average numbers of rice water weevil larvae per core across urea-nitrogen rates was for the numbers to be numerically greatest in rice receiving no insecticide, intermediate for rice treated with thiamethoxam, and lowest for rice treated with clothianidin (Fig. 2.1). The average number of rice water weevil larvae for all three seed-applied insecticide treatments either increased as urea-nitrogen rate increased or increased to the 100 kg urea-nitrogen/ha rate and plateaued. However, the two insecticide-seed treatments behaved differently as urea-nitrogen rate increased. The larval counts in thiamethoxam-treated rice tended to increase as nitrogen rate increased, while larval counts in clothianidin-treated rice generally peaked at the 50 kg urea-nitrogen/ha or 100 kg urea-nitrogen/ha and plateaued or declined when the nitrogen rate was ≥150 kg urea-nitrogen /ha. Three of the six sites (PTRS-12a, PTRS-13a, and RREC-13a) showed a quadratic rice water weevil larval response to urea-nitrogen rate, while the other three sites (PTRS-12b, PTRS-13b, and RREC-13b) showed a linear rice water weevil larval response to urea-nitrogen rate. At PTRS-12b (linear) and RREC-13a (quadratic), the three seed-applied insecticides within each trial behaved similarly across urea-nitrogen rates with the average number of larvae being equal for rice treated with thiamethoxam and clothianidin and significantly lower than rice receiving no insecticide (Table 2.7 and Fig 2.1). For the other four sites, the trend within each experiment for rice water weevil larvae numbers changed among the three seed-applied insecticides (Tables 2.6 and 2.7).

The number of rice water weevil larvae at PTRS-13b and RREC-13b increased positively and linearly but at different rates and magnitudes among seed-applied insecticides as urea-nitrogen rate increased (Tables 2.6 and 2.7). At both sites, rice receiving no insecticide always had the greatest numbers of rice water weevil larvae and the most rapid rate of increase in larvae across urea-nitrogen rates. Thiamethoxam- and clothianidin-treated rice had similar numbers of rice water weevils at 0 kg urea-nitrogen/ha, but numbers of larvae increased at different rates (different linear slope coefficients). Rice treated with thiamethoxam had a higher rate of larval density increase than clothianidin -treated rice as urea-nitrogen rate increased. The larval density of clothianidin -treated rice increased at a slower rate as urea-nitrogen rate increased than thiamethoxam-treated rice or rice that received no insecticide.

PTRS-12a and PTRS-13a had the greatest average numbers of rice water weevil larvae of all sites which increased non-linearly and differently among seed-applied insecticide treatments as urea-nitrogen rate increased (Tables 2.6 and 2.7). The predicted densities of rice water weevil larvae ranged from 9 to 21 larvae per core at PTRS12a and 9 to 18 larvae per core at PTRS-13a across urea-nitrogen rates. At PTRS-12a rice receiving no insecticide had greater numbers of rice water weevil larvae across all urea-nitrogen rates than rice treated with either thiamethoxam or clothianidin (Fig. 2.1). Thiamethoxam or clothianidin-treated rice had similar numbers of rice water weevil larvae until nitrogen rates exceeded 110 kg urea-nitrogen/ha, at which point thiamethoxam-treated rice had a greater larval numbers than clothianidin-treated rice. The trend at PTRS-13a was similar to that described for PTRS-12a except that the average number of rice water weevil larvae per core was similar across all urea-nitrogen rates for thiamethoxam- and clothianidin-treated rice.

Bowling (1963), Rolston and Rouse (1964), and Way et al. (2006) have all reported that rice water weevil larval density tends to be greater in rice that receives near optimal early-season nitrogen rates compared to below optimal nitrogen rates. Way et al. (2006) also reported that an efficacious seed-applied insecticide lowered rice water weevil larval density in rice. In their review of the literature, Way et al. (2006) attributed the increased larval density in rice receiving optimal rates of nitrogen fertilizer to improved insect nutrition which may enhance insect reproduction. Other than enhancing available nutrition, increased nitrogen rate increases plant mass which has also been shown to influence rice water weevil larval density (Bowling 1963) Mazzanti et al. (2012) tested the effect of thiamethoxam seed treatment on rice water weevil control in conventional and hybrid rice. The hybrid had significantly greater tiller number and dry weight than the conventional variety and also resulted in significantly higher rice water weevil larval density. Adding nitrogen also results in greater tillering and dry weight (De Datta 1981, Slaton et al. 2012).

NITROGEN UPTAKE

Nitrogen uptake by rice at the early heading stage varied among the six experiments. The aboveground nitrogen content of rice receiving no urea-nitrogen fertilizer, averaged across seed-applied insecticide treatments, totaled 109 kg nitrogen/ha for PTRS-12a, 89 kg nitrogen/ha for PTRS-12b, 55 kg nitrogen/ha for PTRS-13a, 92 kg nitrogen/ha for PTRS-13b, 61 kg nitrogen/ha for RREC-13a, and 71 kg nitrogen/ha for RREC-13b. The relationship between aboveground nitrogen uptake at early heading and urea-nitrogen fertilizer rate was quadratic for one experiment (PTRS-12b) and linear for the other five experiments (Table 2.6). Regardless of whether the response was linear or quadratic, nitrogen uptake increased as urea-nitrogen rate increased (Fig 2.2.) within the range of applied nitrogen-fertilizer rates. For the sites that showed a linear relationship the slope coefficient (kg nitrogen uptake/kg fertilizer nitrogen applied) indicates the average fertilizer nitrogen uptake efficiency by rice (Table 2.8). The efficiency of nitrogen uptake by rice ranged from 61 to 84% of the applied urea-nitrogen which is consistent with the values stated by Norman et al. (2003) for well-managed rice grown in the direct-seeded, delayed-flood production system.

The main effect of seed-applied insecticide on rice nitrogen uptake was not consistent among all six trials (Table 2.6). As an intercept term, seed-applied insecticide treatment affected the magnitude of nitrogen uptake only at RREC-13b where, regardless of the urea-nitrogen rate and compared to rice from seed that received no insecticide, nitrogen uptake by rice was increased equally by use of either thiamethoxam or clothianidin (Table 2.8). Specific reasons for the benefit of the two insecticide-seed treatments on rice nitrogen uptake at RREC-13b are unknown and do not appear to be related to rice water weevil larvae damage because RREC-13b had low numbers of rice water weevil larvae in all seed-applied insecticide treatments (Table 2.7 and Fig 2.1) and intermediate, but sufficient, stand density (Table 2.3) compared to the other sites.

Seed-applied insecticide affected nitrogen uptake across urea-nitrogen rates only at PTRS-12b and PTRS-13b (Tables 2.6 and 2.8). At PTRS-12b, rice nitrogen uptake at early heading was similar across all urea-nitrogen rates when rice seed was treated with thiamethoam or clothianidin (Fig. 2.2). Nitrogen uptake by rice treated with thiamethoam or clothianidin changed across the range of nitrogen fertilizer rates. For nitrogen rates between 0 and 30 kg urea-nitrogen/acre there was no difference in nitrogen uptake among the three seed treatments, but nitrogen uptake was greater for thiamethoam- or clothianidin -treated rice than seed with no insecticide when nitrogen rates were 30 to 130 kg urea-nitrogen/ha. Aboveground nitrogen uptake among the three seed treatments was again similar until nitrogen rates exceeded 190 kg urea-nitrogen/ha at which point nitrogen uptake was greater for rice that received no insecticide.

At PTRS-13b, rice nitrogen uptake for all seed-applied insecticide treatments was linear with thiamethoxam- and no insecticide-treated seed having similar nitrogen uptakes across the range of applied urea-nitrogen rates. Rice that was treated with clothianidin had similar nitrogen uptakes as the no insecticide and thiamethoxam treatments until nitrogen rates exceeded 84 and 124 kg urea-nitrogen/ha, respectively, at which point nitrogen uptake was greater for rice treated with clothianidin.

This is the first known research that has reported the effect of seed-applied insecticide and urea-nitrogen rate on aboveground nitrogen uptake by rice. Others have reported the effects of these two factors on larval density and rice grain yield, but did not measure season total nitrogen uptake as a possible explanation of the yield increase that is frequently attributed to seed-applied insecticides (Bowling 1963, Way et al. 2006, Lorenz et al 2012,). Yield loss from rice water weevil larvae damage is believed to be from reduced nutrient uptake when the root system is compromised, increased early-season competition from weeds, or both (Way et al. 2006). The PTRS-12a, PTRS-13a, and PTRS-13b sites had the greatest larval densities (Fig 2.1) in the no insecticide control of the six experiments with populations exceeding the five larvae per core threshold suggested for incurring significant rice grain yield loss (Way and Espino 2012). The results for these six experiments suggest that season-total nitrogen uptake was not enhanced by the use of thiamethoam- or clothianidin-treated seed. The lack of a consistent difference in nitrogen uptake among the seed-applied insecticide treatments is perhaps because larval density in rice that received no insecticide was less than 10 larvae per core at three sites and generally less than 20 larvae per core at the other three sites (Fig. 2.1) Alternatively, season-total nitrogen uptake may not be affected by root pruning if the permanent flood is maintained for the duration of the season. The continuous anaerobic soil condition of properly managed, flood-irrigated rice stores soil and fertilizer nitrogen in the ammonium form until it can be taken up by rice. Even though season-total-nitrogen uptake at early heading was not affected this does rule out the possibility that rice grain yields could still be reduced by early-season root pruning. Research has shown that nitrogen uptake during the vegetative growth period sets rice yield potential and nitrogen applied at midseason has limited ability to increase rice yields if early season nitrogen uptake was insufficient (Wilson et al., 1998, Norman et al., 2003). Perhaps measuring rice uptake of nitrogen and other nutrients at an earlier growth stage (e.g., panicle differentiation) would indicate whether early-season nitrogen uptake rate is enhanced and contributing to the positive rice yield responses that have been reported by Way et al. (2006). For example, Slaton et al. (2012) showed that thiamethoam-treated seed produced greater rice dry matter at midtillering and had numerically higher phosphorus and zinc concentrations than plant tissue from untreated seed.

GRAIN YIELD

Rice grain yield response to urea-nitrogen rate differed among the five harvested experiments and was nonlinear (quadratic) for all trials except RREC-13a where the yield response to urea-nitrogen rate was linear (Tables 2.9 and 2.10). Regardless, of the trial and magnitude of absolute rice yield, the effect of seed-applied insecticide was relatively consistent across the five harvested trials (Fig. 2.3). Seed-applied insecticide resulted in yield differences that were uniform across urea-nitrogen rates at all trials except PTRS-13b, where yields were statistically the same for all three seed treatments. Among the other four harvested trials, seed treated with thiamethoam and clothianidin always produced similar yields, but only the thiamethoxam treatment resulted in greater yields than seed receiving no insecticide at all four trials. The yield benefit from the thiamethoxam at four sites ranged from 461 to 567 kg grain/ha above rice that received no insecticide. The grain yields produced by rice receiving the clothianidin seed treatment tended to be intermediate between the no insecticide and thiamethoxam treatments and ranged from 387 to 464 kg/ha greater than yields from the no insecticide treatment at PTRS-12a, PTRS-13a, and RREC-13b. When based on the maximum predicted yield (Table 2.10) within the range of applied urea- nitrogen rates thiamethoxam increased rice yields at four of five sites by an average of 5% and clothianidin increased rice yield at three of five sites by an average of 4.2%.

The regression equations showed the season-total, urea-N rate predicted to produce maximal rice yield was greater than the greatest applied urea-nitrogen rate (200 kg urea-nitrogen/ha) at PTRS-13a, RREC-13a, and RREC-13b. Maximal rice yields were produced by application of 164 kg urea-nitrogen/ha at PTRS-12a and 183 kg urea-nitrogen/acre at PTRS-13b. As shown in previous studies, rice grain yields are often increased when rice seed is treated with insecticides including thiamethoxam or clothianidin in trials that had relatively low rice water weevil larval densities (Lorenz et al. 2012). For example, RREC-13a and RREC-13b both had low (<10 larvae per core) rice water weevil larval pressure in rice that received no seed-applied insecticide which was reduced even more by treatment of seed with thiamethoxam or clothianidin across urea-nitrogen rates. Thus, it appears that the yield increase from thiamethoxam and clothianidin is not dependent upon having high levels of rice water weevil larvae and is not associated with increased nitrogen uptake (Fig. 2.2). Since nitrogen uptake by rice late in the season was not usually affected by the presence or absence of seed-applied insecticide and weeds were controlled in a timely manner to prevent competition with seedling rice, the reason for the measured grain yield benefit of these two insecticides in 60 to 80% of the harvested trials may be from some physiochemical stimulation, the control of other pests that are not currently recognized as limiting rice yield, enhanced early season nutrient uptake, or combinations of factors. Rolston and Rouse (1960) and Bowling (1959) also reported significant rice grain yield increases from seed-applied insecticide despite relatively low rice water weevil larvae numbers.

CONCLUSION

The seed-applied insecticide treatments of thiamethoxam and clothianidin enhanced the final rice stand density in up to 50% of the trials and consistently reduced rice water weevil larval density compared to rice that received no insecticide in six research trials. Clothianidin and thiamethoxam increased maximal rice grain yields in 60 to 80% of the five harvested trials by an average of 4 to 5%, respectively. The use of thiamethoxam and clothianidin did not alter rice response to nitrogen-fertilizer rate in four of the six experiments and had only a small, albeit significant, influence at two sites that was not consistent across the applied urea-nitrogen rates. The increase in rice grain yield from the use of thiamethoxam or clothianidin was not attributed to suboptimal stand density, damaging numbers of rice water weevil larvae, or increased nitrogen uptake by rice. Four of the six experiments had rice water weevil larvae numbers that exceeded the suggested threshold for economic damage. Protecting the rice root system from damage by a high population of rice water weevil larvae would be expected to increase both yield and soil and fertilizer nitrogen uptake. Despite the lack of a consistent benefit of thiamethoxam and clothianidin on nitrogen uptake by early heading, we cannot rule out the possibility that these insecticides may protect the root system from rice water weevil damage during vegetative growth and enhance early-season uptake of nitrogen and perhaps other nutrients, protect the plants from other insects or pathogens that are not recognized as limiting yield, or have some synergistic benefit on plant physiochemical processes that could potentially benefit yield.

The novel aspect of this research is that season total plant nitrogen uptake was measured in an attempt to determine whether these seed treatments might enhance plant uptake of soil and fertilizer nitrogen and be considered a best management practice for managing soil and fertilizer nutrients. The results from these six trials that had relatively low rice water weevil larvae numbers indicate that soil and fertilizer nitrogen uptake were not enhanced by thiamethoxam or clothianidin. However, rice water weevil larvae numbers that cause severe damage to the rice root system occur in selected Arkansas rice fields each year and compromise rice irrigation and nutrient management practices that may require the field to be drained and dried as a means of larvae control or extra nitrogen be applied to maintain early season nutrient uptake and growth rate after the severe root pruning has occurred. Thus, application of thiamethoxam or clothianidin onto rice seed appears to be a viable practice for enhancing stand density, controlling rice water weevil larvae, and providing significant and consistent yield increases in a high percentage of rice fields.

BIBLIOGRAPHY

Bender, R.R., J.W. Haegele, M.L. Ruffo, and F.E. Below. 2013. Nutrient uptake, partitioning, and remobilization in modern, transgenic insect-protected maize hybrids. Agron. J. 105:161–170.

Bowling, C.C., 1957. Seed treatment control of the rice water weevil. J. Econ. Entomol. 50(4):450-452.

Bowling, C.C., 1959. A comparison of three methods of insecticide application for control of the rice water weevil. New Jersey Agricultultural Experiment Station, Rutgers, NJ.

Bowling, C.C., 1963. Effect of nitrogen levels on rice water weevil populations. J. Econ. Entom. 56: 826-827.

Brandl, F. 2001. Seed treatment technologies: evolving to achieve crop genetic potential, pp. 3-18. *In* Proceedings, British Crop Protection Council Symposium No. 76, 26-27 February 2001, North Warwickshire, UK., British Crop Protection Council, Farnham, England.

Buresh, R.J. and De Datta, S.K. 1990. Denitrification losses from puddled rice soils in the tropics. Biol. Fertil. Soils, 9: 1–13.

Chang, Te-Tzu. 2000. Staple foods: domesticated plants and animals: grains: rice, pp. 132-149. *In* K.F. Kiple and K.C. Ornelas (eds.), The Cambridge World History of Food. Cambridge University Press, New York, NY.

Choudhury, A. T. M. A., and I.R Kennedy. 2005. Nitrogen fertilizer losses from rice soils and control of environmental pollution problems. Communications in Soil Science and Plant Analysis 36: 1625-639.

Davis, B.M., R.C. Scott, and J.W. Dickson. 2011. Rotational options for reducing red rice (*Oryza sativa*) in Clearfield rice production systems, pp. 155-158. *In* R.J. Norman and K.A.K. Moldenhauer(eds.), B.R. Wells Rice Research Studies 2011, Research Series 600, Arkansas Agricultural Experiment Station, Fayetteville, AR.

De Datta, S.K. 1981. Principles and practices of rice production. John Wiley & Sons, New York.

Dillon, K.A., T.W. Walker, D.L. Harrell, L.J. Krutz, J.J. Varco, C.H. Koger, and M.S. Cox. 2012. Nitrogen sources and timing effects on nitrogen loss and uptake in delayed flood rice. Agronomy Journal 104.2: 466-72.

Elbert, A., M. Haas, B. Springer, W. Thielert, and R. Nauen. 2008. Mini-review: applied aspects of the neonicotinoid uses in crop protection. Pest Manag Sci 64:1099–1105.

Fortner, J., G.M. Lorenz III, K. Colwell, and N. Taillon. 2011. Efficacy of selected insecticide seed treatments for the control of rice water weevil across three seeding rates in Arkansas rice, 2010, pp. 97-100. *In* R.J. Norman and K.A.K. Moldenhauer (eds.), B.R. Wells Rice Research Studies 2010, Research Series 591, Arkansas Agricultural Experiment Station, Fayetteville, AR.

Frizzell, D.L, C.E. Wilson, Jr., R.J. Norman, N.A. Slaton, A.L. Richards, J.L. Hill, J.W. Branson, and S.K. Runsick. 2006. Influence of rice spacing and seeding rate on rice grain yield, pp. 270-275. *In* R.J. Norman, J.F. Meullenet and K.A.K. Moldenhauer (eds.), B.R. Wells Rice Research Studies 2005, Research Series 540, Arkansas Agricultural Experiment Station, Fayetteville, AR.

Gifford, J. R., B. F. Oliver, and G. B. Trahan. 1975. Control of larvae of the rice water weevil establishd (*sic*) among rice roots and effect on yield. J. Econ. Entomol. 68: 82-84.

Guindo, D., R.J. Norman, and B.R.Wells. 1994. Accumulation of fertilizer nitrogen-15 by rice at different stages of development. Soil Sci. Soc. Am. J. 58:410–415.

Haegele, J.W., and F.E. Below. 2013. Transgenic corn rootworm protection increases grain yield and nitrogen use of maize. Crop Sci. 53:585-594.

Hardke, J.T., C.E. Wilson Jr. 2013a. Introduction, pp. 1-8. *In* J.T. Hardke (ed.), Arkansas Rice Production Handbook, Extension Misc. Pub. 192. University of Arkansas Division of Agriculture Cooperative Extension Service, Little Rock, AR.

Hardke, J.T., and C.E. Wilson, Jr. 2013b. Trends in Arkansas Rice Production, pp. 38-47. *In* R.J. Norman and K.A.K. Moldenhauer (eds.), B.R. Wells Rice Research Studies 2012, Research Series 609, Arkansas Agricultural Experiment Station, Fayetteville, AR.

Isely D., and H.H. Schwardt. 1930. The tracheal system of the larva of *Lissorhoptrus simplex*. Annals of the Entom. Soc. of Am. 23: 149-152.

Isely, D., and H.H. Schwardt. 1932. The rice water weevil problem in Arkansas. J. Econ. Entomol. 25(2): 218-222.

Isely, D., and H.H. Schwardt. 1934. The rice water weevil. Arkansas Agricultural Experiment Station Bulletin 299. Fayetteville, AR.

Lorenz, G.M., A. Plummer, N. Taillon, B. Thrash, J. Fortner, and K. Colwell. 2012. Comparison of insecticide seed treatments and foliar applications for control of rice water weevil, pp. 116-119. *In* R.J. Norman and K.A.K. Moldenhauer (eds.), B.R. Wells Rice Research Studies 2011, Research Series 600, Arkansas Agricultural Experiment Station, Fayetteville, AR.

Lorenz, G.M. and J. Hardke. 2013. Insect management in rice, pp. 139-162. *In* J.T. Hardke (ed.), Arkansas Rice Production Handbook, Extension Misc. Pub. 192. University of Arkansas Division of Agriculture Cooperative Extension Service, Little Rock, AR.

Mae, T. 1997. Physiological nitrogen efficiency in rice: nitrogen utilization, photosynthesis, and yield potential. Plant and Soil 196: 201-210.

Mazzanti, R.S., J.L. Bernhardt, and S. Ntamatungiro. 2012. Effect of thiamethoxam seed treatment on rice water weevil control in conventional and hybrid rice varieties, pp. 120-127. *In* R.J. Norman and K.A.K. Moldenhauer (eds.), B.R. Wells Rice Research Studies 2011, Research Series 600, Arkansas Agricultural Experiment Station, Fayetteville, AR.

Moldenhauer, K., C. E. Wilson Jr., P. Counce, and J. Hardke. 2013. Rice growth and development, pp. 9-20. *In* J.T. Hardke (ed.), Arkansas Rice Production Handbook, Extension Misc. Pub. 192. University of Arkansas Division of Agriculture Cooperative Extension Service, Little Rock, AR.

Morgan, D.R., N.P. Tugwell, and J.L. Bernhardt. 1989. Early rice field drainage for control of rice water weevil. (Coleoptera: Curculionidae) and evaluation of an action threshold based upon leaf-feeding scars of adults. J. Econ. Entomol. 82(6):1757-1759.

Norman, R.J, Wilson, C.E. Jr., and N.A. Slaton. 2003. Soil fertilization and mineral nutrition in the U.S. mechanized rice culture, pp. 331-411. *In* C.W. Smith and R.H. Dilday (eds.), Rice: Origin, History, Technology, and Production. John Wiley & Sons, Inc., Hoboken, NJ.

Norman, R., N. Slaton, and T. Roberts. 2013. Soil fertility, pp. 69-101. *In* J.T. Hardke (ed.), Arkansas Rice Production Handbook, Extension Misc. Pub. 192. University of Arkansas Division of Agriculture Cooperative Extension Service, Little Rock, AR.

Pathak, M.D. and Z. R. Khan. 1994. Insect pests of rice. International Rice Research Institute and ICIPE. Manilla, Philipines,

Plummer, W.A., G.M. Lorenz III, N.M. Taillon, B.C. Thrash, J.W. Fortner, and C.K. Colwell. 2012. Impact of insecticide seed treatments in large block field trials in Arkansas, 2009 to 2011. pp. 128-131. *In* R.J. Norman and K.A.K. Moldenhauer(eds.), B.R. Wells Rice Research Studies 2011.

Rolston, L.H, and P. Rouse. 1960. Effect of insecticidal seed treatments on rice. J. Kansas Entomol. Soc. 33(3):119-122.

Rolston, L.H., and P. Rouse. 1964. Some factors influencing larval infestations of the rice water weevil. J. Kans. Entomol. Soc. 37: 29-35.

Saito, T., K. Hirai, and M.O. Way. 2005. The rice water weevil, *Lissorhotrus oryzophilus* Kuschel (Coleoptera: Curculionidae). Appl. Entomol. Zool. 40(1): 31-39.

Scott, B., J. Norsworthy, T. Barber, and J. Hardke. 2013. Rice weed control, pp. 53-62. *In* J.T. Hardke (ed.), Arkansas Rice Production Handbook, Extension Misc. Pub. 192. University of Arkansas Division of Agriculture Cooperative Extension Service, Little Rock, AR.

Shi, W. M., W. F. Xu, S. M. Li, X. Q. Zhao, and G. Q. Dong. 2010. Responses of two rice cultivars differing in seedling-stage nitrogen use efficiency to growth under low-nitrogen conditions. Plant Soil 326: 291-302.

Shivrain, V.K., N.R. Burgos, K.A. Moldenhauer, R.W. McNew, and T.L. Baldwin. 2006. Characterization of spontaneous crosses between Clearfield rice (*Oryza sativa*) and red rice (*Oryza sativa*). Weed Tech. 20:576-584.

Slaton, N.A., R.D. Cartwright, J. Meng, E.E. Gbur, Jr., and R.J. Norman. 2003. Effect of nitrogen fertilizer rate, method of application, and fungicide rate on rice grain yield and sheath blight severity. Agron. J. 95:1489-1496.

Slaton, N.A., E.E. Gbur, Jr., R.D. Cartwright, R.J. Norman, K.R. Brye, and R.E. DeLong. 2004. Effect of nitrogen fertilizer rate and method of application on rice grain yield and kernel smut. Agron. J. 96:1489-1496.

Slaton, N.A., T.L. Roberts, R.J. Norman, R.E. DeLong, C.G. Massey, D.L. Frizzell, S. Clark, and J Shafer. 2012. Rice growth and yield response to CruiserMaxx seed treatment and fertilization. pp. 265-270. *In* R.J. Norman and K.A.K. Moldenhauer(eds.), B.R. Wells Rice Research Studies 2011.

Smith, K.A., A.A. Grigarick, J.H. Lynch, and M.J. Oraze. 1985. Effect of alsystin and diflubenzuron on the rice water weevil. J. Econ. Entomol. 78:185-189.

Stout, M.J., W.C. Rice, R.M. Riggio, and D.R. Ring. 2000. The effects of four insecticides on the population dynamics of the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel. J. Entomol. Sci. 35: 48-61.

Stout, M.J., M.R. Riggio, L. Zou, and R. Roberts. 2002. Flooding influences ovipositional and feeding behavior of the rice water weevil (Coleoptera: Curculionidae). J. Econ. Entomol. 95(4): 715-721.

Taillon, N.M., G.M. Lorenz III, A. Plummer, M. Everett, B. Thrash, D. Clarkson, and L.Orellana-Jimenez. 2013. Comparison of insecticide seed treatments and foliar applications for control of rice water weevil, pp. 119-121. *In* R.J. Norman and K.A.K. Moldenhauer (eds.), B.R. Wells Rice Research Studies 2012, Research Series 609, Arkansas Agricultural Experiment Station, Fayetteville, AR.

Thompson, R. A., S. S. Quisenberry, G. B. Trahan, A. M. Heagler, and G. Giesler. 1994. Water management as a cultural control tactic for the rice water weevil (Coleoptera: Curculionidae) in Southwest Louisiana. J. Econ. Entomol. 87: 223-230.

Thompson, R.A., and S.S. Quisenberry. 1995. Rice plant density effect on rice water weevil (Coleoptera: Curculionidae) infestation. Environ. Entomol. 24: 19-23.

Tindall, K.V. and M.J. Stout. 2003. Use of common weeds of rice as hosts for the rice water weevil (Coleoptera: Curculionidae). Environ. Entomol. 32(5): 1227-1233.

(USDA ERS) U.S. Department of Agriculture. Economic Research Service. http://www.ers.usda.gov/topics/crops/rice/#
Accessed: April 1, 2014

(USDA) U.S. Department of Agriculture. 2009. 2007 Census of Agriculture. USDA-NASS, Washington, DC.

(USEPA) U.S. Environmental Protection Agency. 1989 . Carbofuran – position document 2/3. USEPA, Washington, D.C.

Wamishe, Y., R. Cartwright, and F. Lee. Management of rice diseases, pp 123-137. *In* J.T. Hardke (ed.), Arkansas Rice Production Handbook, Extension Misc. Pub. 192. University of Arkansas Division of Agriculture Cooperative Extension Service, Little Rock, AR.

Way, M.O., and C.C. Bowling. 1991. Insect pests of rice, pp 237-268. *In* B.S. Luh (ed.) Rice: Production. Springer, U.S.

Way, M.O. 2002. Rice arthropod pests and their management in the United States, pp. 437-443. *In* C.W. Smith and R.H. Dilday (eds.), Rice: Origin, History, Technology, and Production. John Wiley & Sons, Inc., Hoboken, NJ.

Way, M.O., F.P.F. Reay-Jones, M. Stout, and L. Tarpley. 2006. Effects of nitrogen fertilizer applied before permanent flood on the interaction between rice and rice water weevil (Coleoptera: Curculionidae). J. Econ. Entomol. 99(6): 2030-2037.

Way, M.O. and L. Espino. 2012. Insect management, pp. 37-52. *In* M.O. Way and G.N. McCauley (eds.), Texas Rice Production Guidelines, Texas AgriLife Research and Extension Center , Beaumont, TX.

Webb, J. L. 1920. How insects affect the rice crop. U.S. Dept. of Agriculture. Washington D.C., U.S.

Whitehead, F. E., 1954. Tests on insecticidal control of the rice water weevil. J. Econ. Entomol. 47: 676-680.

Wilf, H., G.M. Lorenz III, K. Colwell, and N. Taillon. 2009. Efficacy of rice insecticide seed treatments for control of grape colaspis (*Colaspis brunnea*) and rice water weevil (*Lissorhoptrus oryzophilus* Kuschel), pp. 135-139. *In* R.J. Norman, J.F. Meullenet, and K.A.K. Moldenhauer (eds.), B.R. Wells Rice Research Studies 2008, Research Series 571, Arkansas Agricultural Experiment Station, Fayetteville, AR.

Wilf, H., G.M. Lorenz III, K. Colwell, and N. Taillon. 2010. Efficacy of rice insecticide seed treatments for control of grape colaspis and rice water weevil. pp. 109-113. *In* R.J. Norman, J.F. Meullenet, and K.A.K. Moldenhauer (eds.), B.R. Wells Rice Research Studies 2009, Research Series 581, Arkansas Agricultural Experiment Station, Fayetteville, AR.

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

Wilson, C.E. Jr., Y. Wamishe, G. Lorenz, and J. Hardke. 2013. Rice stand establishment, pp. 31-40. *In* J.T. Hardke (ed.), Arkansas Rice Production Handbook, Extension Misc. Pub. 192. University of Arkansas Division of Agriculture Cooperative Extension Service, Little Rock, AR.

Table 2.1. Selected soil and trial management information from six research sites at the Pine Tree Research Station (PTRS)
or the Rice Research and Extension Center (RREC) in 2012 (12) or 2013 (13).

Site-year	Soil series	Plant date	Emerge date	Stand Count		Preflood N	Larvae counts	Plant Sample
				Time 1	Time 2			
				month/day				
PTRS-12a	Calhoun	4/4	4/14	4/16	4/24	5/18	6/11	7/11
PTRS-12b	Calloway	4/23	4/30	5/01	5/11	5/23	6/13	7/12
PTRS-13a	Calhoun	4/16	5/03	5/13	5/20	6/04	6/25	7/16
PTRS-13b	Calloway	4/30	5/12	5/20	5/27	6/12	7/02	8/11
RREC-13a	Dewitt	3/28	4/16	4/29	5/13	5/30	6/24	7/19
RREC-13b	Dewitt	4/16	4/30	5/13	5/20	6/04	6/24	7/25

Table 2.2. Analysis of variance *P*-values of trial, seed-applied insecticide (SAI), and the interaction of trial and SAI (Trial × SAI) for stand density at the two-leaf stage (SD1), stand density at the three-leaf stage (SD2), plant height at the two-leaf stage (PH1), and plant height at the three-leaf stage (PH2) for six trials conducted at the Rice Research and Extension Center (RREC) and Pine Tree Research Station (PTRS) in 2012 and 2013.

Source	SD 1	SD2	PH1	PH2
Trial	<0.0001	<0.0001	<0.0001	<0.0001
SAI	0.0004	0.0034	0.2493	0.0404
Trial × SAI	0.4199	0.0499	0.5111	0.0744

Table 2.3. Stand density as affected by seed-applied insecticide (SAI) at the two-leaf stage, averaged across trials, or at the three-leaf stage as affected by the interaction between SAI and trial, for six experiments conducted at the Rice Research and Extension Center (RREC) and Pine Tree Research Station (PTRS) in 2012 (12) and 2013 (13).

	2-leaf stage	3-leaf stage					
SAI		PTRS-12a	PTRS-12b	PTRS-13a	PTRS-13b	RREC-13a	RREC-13b
		Seedlings per m^2					
None	119 b	156 b [ab]	185 b	115 a	105 a	200 a	143 b
Thiamethoxam	131 a	174 a	193 ab	115 a	105 a	197 a	165 a
Clothianidin	130 a	169 ab	206 a	113 a	117 a	199 a	156 ab

[a] the LSD 0.05 to compare any two means for the 3-leaf stage is 29 seedlings per m2.

[b] Within each column (Site) means are statistically similar when followed by the same letter or different when followed by a different letter.

Table 2.4. Plant height as affected by seed-applied insecticide (SAI), averaged across six trials conducted in 2012 and 2013 at the Rice Research and Extension Center and Pine Tree Research Station.

SAI	2-leaf stage	3-leaf stage
	cm	
None	6.0 a [a]	11.2 b
Thiamethoxam	6.0 a	11.6 a
Clothianidin	6.1 a	11.5 ab

[a] Within each column, means are statistically similar when followed by the same letter or different when followed by a different letter.

Table 2.5. Plant height as affected by trial, averaged across seed-applied insecticide, across six trials conducted at the Rice Research and Extension Center (RREC) and Pine Tree Research Station (PTRS) in 2012 (12) and 2013 (13).

Trial	2-leaf stage	3-leaf stage
	cm	
PTRS-12a	3.8 a [a]	7.0 a
PTRS-12b	4.0 b	16.8 b
PTRS-13a	6.5 ce	10.9 cde
PTRS-13b	7.1 cde	12.0 de
RREC-13a	6.8 c	9.9 c
RREC-13b	7.5 cd	12.1d

[a] Within each column, means are statistically similar when followed by the same letter or different when followed by a different letter.

Table 2.6. Analysis of variance *P*-values for the average number of rice water weevil larvae per core and aboveground nitrogen (N) uptake at early heading for each trial as affected by seed-applied insecticide (SAI), the linear and quadratic functions of nitrogen rate (NR), and their significant interactions as defined by the final simplest model for six trials conducted at the Pine Tree Research Station (PTRS) and the Rice Research and Extension Center (RREC) in 2012 (12) or 2013 (13).

Source	df[a]	PTRS-12a	PTRS-12b	PTRS-13a	PTRS-13b	RREC-13a	RREC-13b
Larvae number							
SAI	2	0.1064	<0.0001	0.0080	0.3413	<0.0001	0.0205
NR	1	<0.0001	0.0014	0.0067	0.0490	0.0004	<0.0001
SAI × NR	2	0.0077	NS[b]	0.0220	0.0792	NS	0.0720
NR^2	1	0.0002	NS	0.0534	NS	0.0241	NS
SAI × NR^2	2	0.0085	NS	NS	NS	NS	NS
Aboveground N Uptake							
SAI	2	0.9669	0.9859	0.3803	0.3782	0.4365	0.0371
NR	1	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
SAI × NR	2	NS	0.0623	NS	0.0222	NS	NS
NR^2	1	NS	0.4486	NS	NS	NS	NS
SAI × NR^2	2	NS	0.0130	NS	NS	NS	NS

[a] df, degrees of freedom

[b] NS, the term was not significant (P>0.10) and was omitted from the model

Table 2.7. Regression coefficients and standard errors for the average number of rice water weevil larvae per core for six trials as affected by seed-applied insecticide (SAI) and nitrogen rate at the Pine Tree Research Station (PTRS) and the Rice Research and Extension Center (RREC) in 2012 (12) and 2013 (13).

Site-year	SAI	Regression coefficient (Standard Error)		
		Intercept	Linear	Quadratic
PTRS-12a	None	8.6 (1.9)	0.2877 (0.0482)	-0.00200 (0.00031)
	Clothianidin	3.5 (1.9)	0.0850 (0.0482)	-0.00200 (0.00031)
	Thiamethoxam	4.0 (1.9)	0.0641 (0.0488)	-0.00200 (0.00031)
PTRS-12b	None	3.6 (0.4)	0.0114 (0.0034)	NS[a]
	Clothianidin	1.0 (0.4)	0.0114 (0.0034)	NS
	Thiamethoxam	1.3 (0.4)	0.0114 (0.0034)	NS
PTRS-13a	None	8.6 (1.7)	0.1183 (0.0316)	-0.00037 (0.00019)
	Clothianidin	2.2 (1.7)	0.0605 (0.0316)	-0.00037 (0.00019)
	Thiamethoxam	3.3 (1.7)	0.0669 (0.0316)	-0.00037 (0.00019)
PTRS-13b	None	8.7 1.6)	0.0417 (0.0151)	NS
	Clothianidin	6.0 (1.6)	-0.0076 (0.0151)	NS
	Thiamethoxam	6.3 (1.6)	0.0187 (0.0151)	NS
RREC-13a	None	5.0 (0.7)	0.0588 (0.0157)	-0.00024 (0.00010)
	Clothianidin	1.6 (0.7)	0.0588 (0.0157)	-0.00024 (0.00010)
	Thiamethoxam	2.6 (0.7)	0.0588 (0.0157)	-0.00024 (0.00010)
RREC-13b	None	3.2 (0.7)	0.0247 (0.0064)	NS
	Clothianidin	1.0 (0.7)	0.0070 (0.0060)	NS
	Thiamethoxam	1.0 (0.7)	0.0243 (0.0059)	NS

[a] NS, quadratic coefficient was not significant

Table 2.8. Regression coefficients and standard errors for mean aboveground nitrogen uptake at early heading for six trials as affected by seed-applied insecticide (SAI) and nitrogen rate at the Pine Tree Research Station (PTRS) and the Rice Research and Extension Center (RREC) in 2012 (12) and 2013 (13).

Site-year	SAI	Regression coefficient (Standard Error)		
		Intercept	Linear	Quadratic
PTRS-12a	None	102 (13)	0.837 (0.057)	NS [a]
	Clothianidin	104 (13)	0.837 (0.057)	NS
	Thiamethoxam	104 (13)	0.837 (0.057)	NS
PTRS-12b	None	83 (10)	0.410 (0.238)	0.00232 (0.0011)
	Clothianidin	81 (10)	1.120 (0.233)	-0.0020 (0.0011)
	Thiamethoxam	82 (10)	1.104 (0.233)	-0.0018 (0.0011)
PTRS-13a	None	49 (8)	0.723 (0.046)	NS
	Clothianidin	51 (8)	0.723 (0.046)	NS
	Thiamethoxam	60 (8)	0.723 (0.046)	NS
PTRS-13b	None	86 (8)	0.612 (0.062)	NS
	Clothianidin	78 (8)	0.830 (0.061)	NS
	Thiamethoxam	94 (8)	0.616 (0.065)	NS
RREC-13a	None	53 (6)	0.787 (0.043)	NS
	Clothianidin	62 (6)	0.787 (0.043)	NS
	Thiamethoxam	60 (7)	0.787 (0.043)	NS
RREC-13b	None	55 (8)	0.673 (0.037)	NS
	Clothianidin	68 (8)	0.673 (0.037)	NS
	Thiamethoxam	71 (8)	0.673 (0.037)	NS

[a] NS, quadratic coefficient was not significant

Table 2.9. Analysis of variance *P*-values for grain yield as affected by trial, seed-applied nsecticide (SAI), the linear and quadratic functions of nitrogen rate (NR), and their significant interactions as defined by the final simplest model for five harvested trials at the Pine Tree Research Station (PTRS) and the Rice Research and Extension Center (RREC) in 2012 (12) and 2013 (13).

Source	df[a]	Yield
Site-year	4	<0.0001
SAI	2	<0.0001
Trial × SAI	8	0.6382
NR	1	<0.0001
Trial × NR	4	<0.0001
SAI × NR	2	NS[b]
Trial × SAI × NR	8	NS
NR × NR	1	<0.0001
Trial × NR^2	4	<0.0001
SAI × NR^2	2	NS
Trial × SAI × NR^2	8	NS

[a] df, degrees of freedom

[b] NS, not significant. The term was not significant (P>0.10) and was omitted from the model.

Table 2.10. Regression coefficients fort rice grain yield as affected by seed-applied insecticide (SAI) and nitrogen rate at the Pine Tree Research Station (PTRS) and the Rice Research and Extension Center (RREC) in 2012 (12) and 2013 (13).

		Regression coefficient (Standard Error) [a]		
Site-year	SAI	Intercept	Linear	Quadratic
PTRS-12a	None	5889 (282)		
	Clothianidin	6353 (282)	41.7 (4.0)	-0.1275 (0.0188)
	Thiamethoxam	6425 (282)		
PTRS-12b	None	NS[b]		
	Clothianidin	NS	NS	NS
	Thiamethoxam	NS		
PTRS-13a	None	4120 (282)		
	Clothianidin	4539 (282)	64.0 (4.0)	-0.1520 (0.0188)
	Thiamethoxam	4687 (282)		
PTRS-13b	None	7740 (282)		
	Clothianidin	7875 (282)	37.9 (4.0)	-0.1035 (0.0188)
	Thiamethoxam	7744 (282)		
RREC-13a	None	2540 (298)		
	Clothianidin	2797 (298)	45.7 (4.3)	-0.0153 (0.0197)
	Thiamethoxam	3001 (298)		
RREC-13b	None	4441 (301)		
	Clothianidin	4828 (301)	41.1 (4.4)	-0.0440 (0.0201)
	Thiamethoxam	4942 (301)		

[a] All intercept, linear and quadratic coefficients were significant (*P*<0.0001) and different than zero except for the quadratic coefficients for RREC-13b (*P*=0.0295, significant and > 0) and RREC-13a (*P*=0.4369, not significant or different than zero).

[b] NS, Yield data were not statistically analyzed due to feral hog damage.

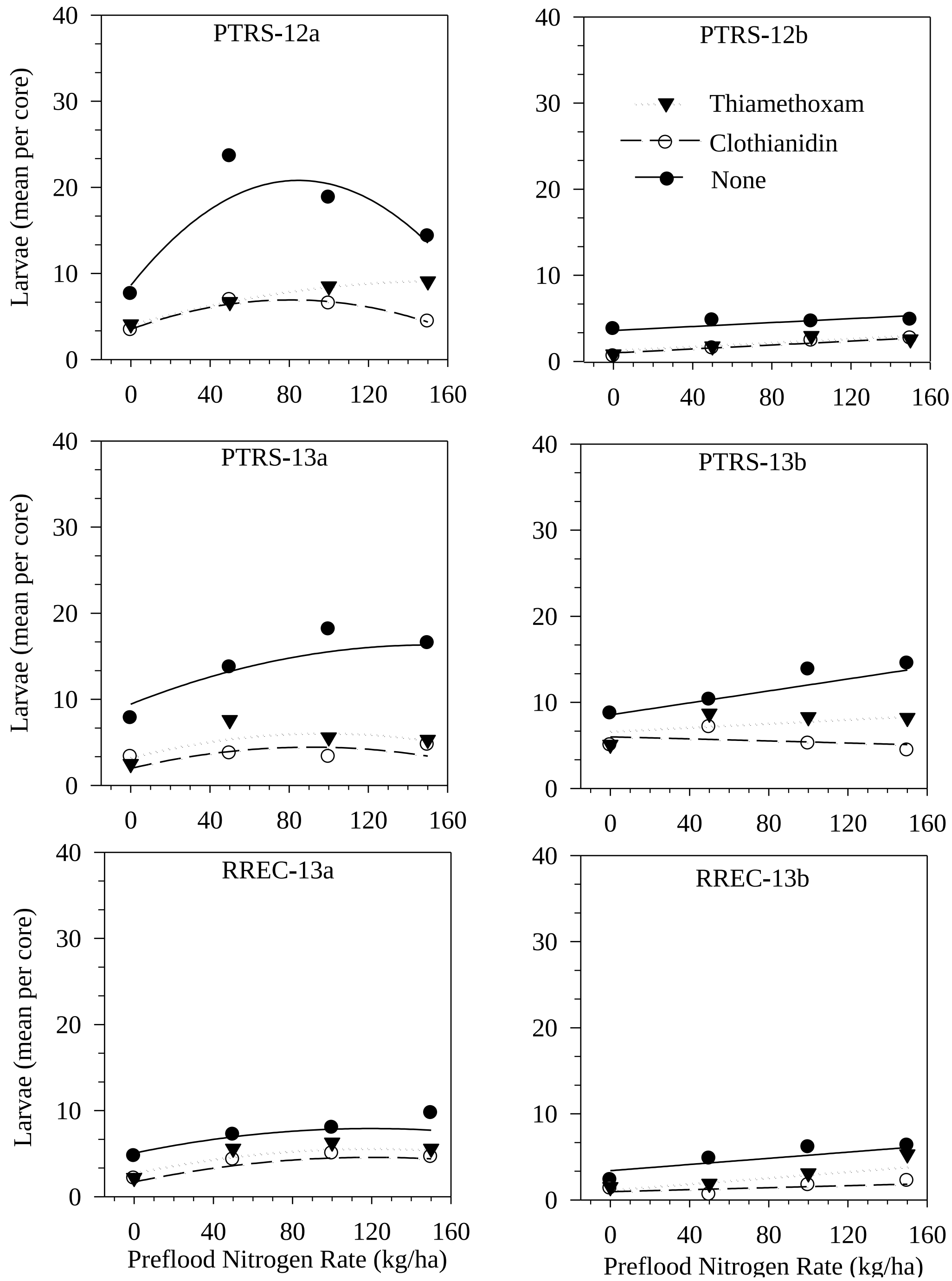

Fig. 2.1. The average number of rice water weevil larvae per core 21 d after flooding rice at six research sites at the Pine Tree Research Station (PTRS) or the Rice Research and Extension Center (RREC) in 2012 (12) or 2013 (13)as affected by nitrogen fertilizer rate and seed- applied insecticide treatment.

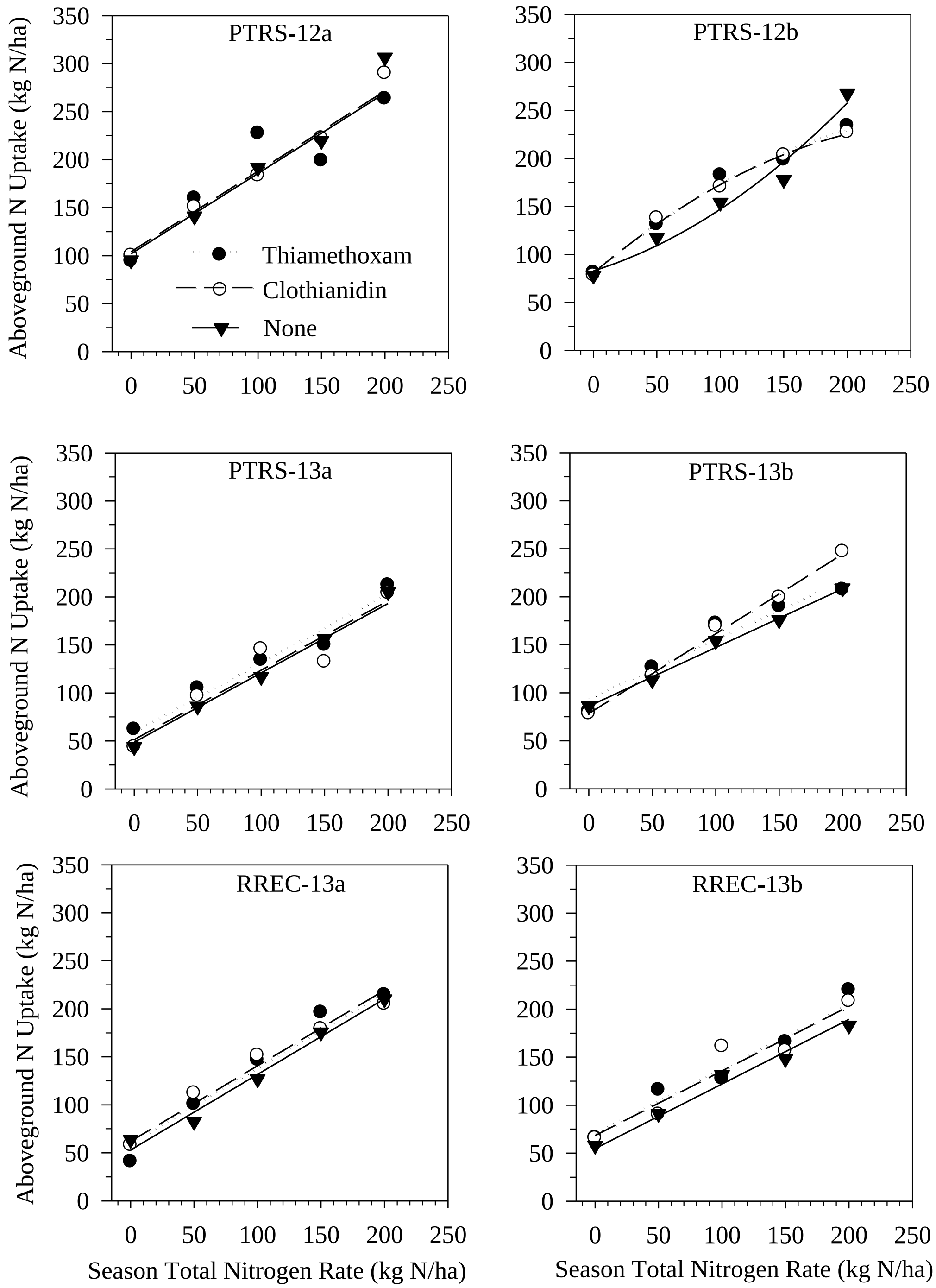

Fig. 2.2. Rice aboveground nitrogen uptake at the early heading stage in six research sites at the Pine Tree Research Station (PTRS) or the Rice Research and Extension Center (RREC) in 2012 (12) or 2013 (13) as affected by nitrogen fertilizer rate and seed-applied insecticide treatment.

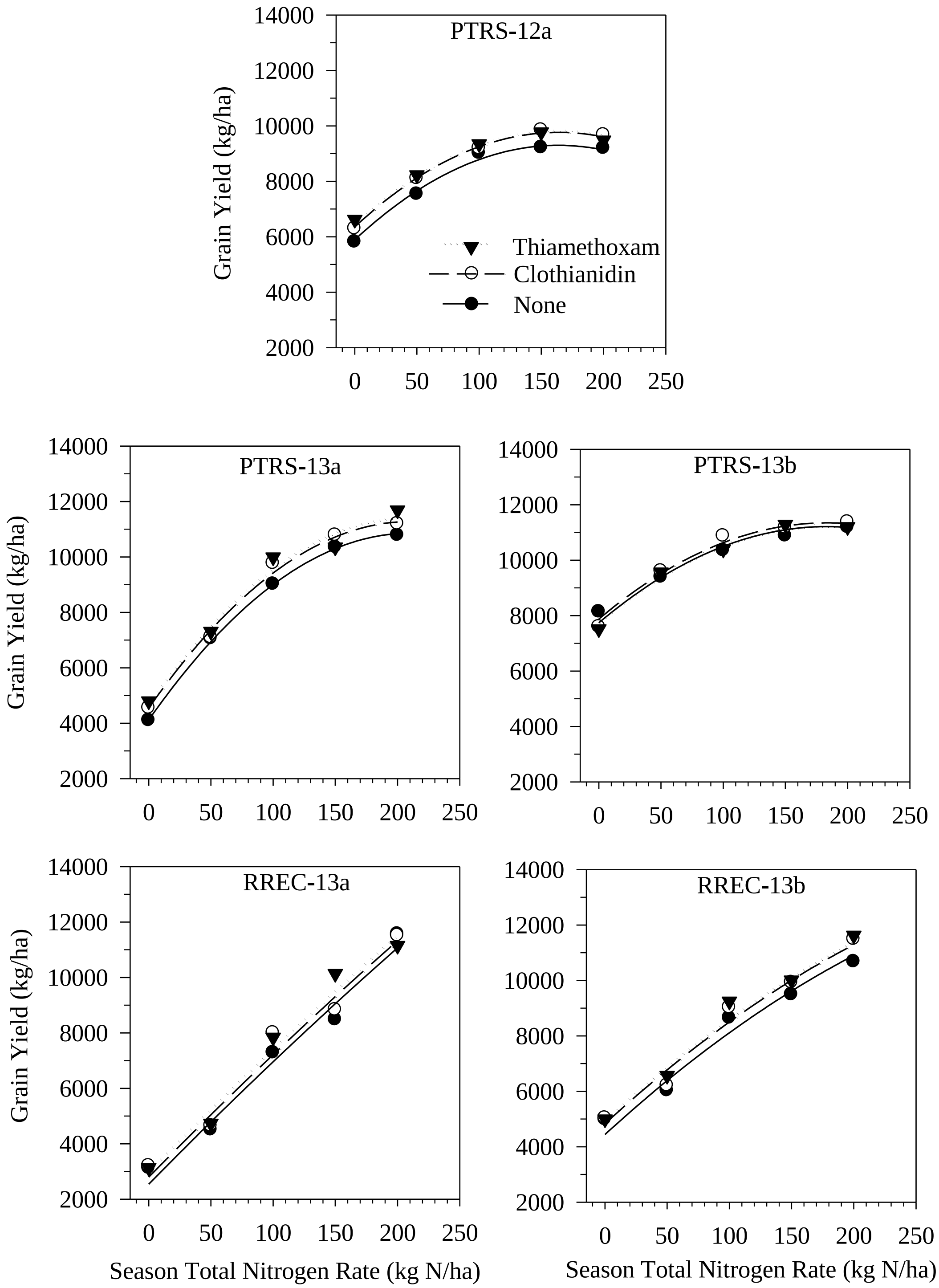

Fig. 2.3. Rice grain yield information for five harvested research sites at the Pine Tree Research Station (PTRS) or the Rice Research and Extension Center (RREC) in 2012 (12) or 2013 (13) as affected by nitrogen fertilizer rate and seed-applied insecticide treatment.

Appendix 2.1. Herbicide management information for six research sites at the Pine Tree Research Station (PTRS) or the Rice Research and Extension Center (RREC) in 2012 (12) or 2013 (13).

Site-year	Herbicide	Date
PTRS-12a	6 oz/A Newpath	4/5/12
	1qt/A Prowl, 3 qt/A Stam, 0.33 lb/A Facet	4/19/12
	2 pt/A Bolero and 2 qt/A propanil	5/12/12
PTRS-12b	4 oz/A Newpath	4/23/12
	4 oz/A Newpath and 3qt/A Riceshot	5/23/12
PTRS-13a	6 oz/A Newpath and 3 qt/A Propanil	5/1/2013
	0.75 oz/A Londax, 6 oz/A Newpath, and 2 qt/A Propanil	5/25/13
PTRS-13b	0.33 lb/A Facet and 2 pt/A Prowl	04/26/13
	3 qt/A Rice shot and 0.75 oz/A Permit	05/20/13
RREC-13a	20oz/A Obey	4/10/13
	24 oz/A RiceStar, 25 oz/A Facet L, and 3 qt/A RiceShot	05/29/13
	0.67 oz/A Permit Plus	05/31/13
RREC-13b	20 oz/A Obey	04/17/13
	24 oz/A RiceStar, 25 oz/A Facet L, 3 qt/A RiceShot	05/29/13
	0.67 oz/A Permit Plus	05/31/13