3-9-2022

Impact of New Technologies on Weed Control in Louisiana Rice Production

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IMPACT OF NEW TECHNOLOGIES ON WEED CONTROL IN LOUISIANA RICE PRODUCTION

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Plant, Environmental and Soil Sciences

by
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May 2022

Acknowledgements

I would like to extend my thanks to the many people who supported me and made this work possible. First, I would like to thank my parents, John and Deanna Walker, for their encouragement, love, and support throughout my academic career. I also would like to thank my close friend and colleague Dr. Joey Williams for helping me push through the writing process and for assisting me with statistical analysis. Furthermore, I would like to thank my close friends Rob Berner, John Edwards, Ryan Daniel, and Connor “Rooster” Morgan for their tough love and encouragement through my academic career and for keeping me sane when I was discouraged.

I would like to especially thank Dr. Eric Webster for supporting me and mentoring me throughout my time at Louisiana State University. Thank you for giving me an ample number of opportunities to present research and interact with other professionals within the industry. I am especially grateful for your knowledge and wisdom in the plant science field that you shared so that I could develop the skills needed to work in this profession. I am also appreciative of the members of my committee, Dr. Daniel Stephenson, Dr. Adam Famoso and Dr. Achyut Adhikari. Thank you for your ideas and instruction in the development and fulfillment of this research.

This work would not have been possible without the assistance of fellow graduate students Bradley Greer, Matthew Osterholt, Sam Rustom and Connor Webster. I would also like to thank John Sonnier for his time and efforts with completing this research and the Louisiana Rice Research Board for their financial support of this research.

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Abstract

Field studies were conducted in 2018-2021 at the LSU Agricultural Center's H.R. Caffey Rice Research Station (RRS) near Crowley, LA, and the Dean Lee Research and Extension Center (DLREC) near Alexandria, LA to evaluate off-target florpyrauxifen movement on soybean. Soybean was treated with florpyrauxifen at the V4-V5 or R1-R2 growth stages. Soybean injury was evaluated at 1, 7, 14, and 28 days after treatment (DAT) and soybean plant height (cm) was recorded at 7, 14, and 28 DAT. At soybean maturity, yield and individual yield components were subjected to regression analysis to describe the relationship between florpyrauxifen rate and soybean yield. Crop injury was observed at all evaluation dates. Soybean yield was reduced with florpyrauxifen applied at 1.84 g ha^{-1} at the V4-V5 timing and florpyrauxifen applied at 0.46 g ha^{-1} or more at the R1-R2.

Field studies were conducted in 2019 and 2020 at the RRS and the DLREC to evaluate florpyrauxifen volatilization following an application to rice foliage, exposed soil, or exposed water. Soybean was the bioindicator, treated application media was placed in the center of plots and distance moved was measured via injury ratings at 31 cm increments. Results indicated that florpyrauxifen has minimal volatilization with injury observed at 31 cm from the plot center with no differences between medias.

Field studies were conducted in 2019 and 2021 at the RRS and the Northeast research station (NERS) near St. Joseph, LA to evaluate quizalofop activity on rice. Two inbred lines and a hybrid rice were treated with quizalofop applied at 0 to 116 g ha^{-1} to rice in different growth stages. Control and plant heights were recorded 7, 14, 21, and 28 DAT. Control was 90 to 99% when CL-111 and CLXL-745 were treated with quizalofop at least 23 g ha^{-1} at the two- to three-leaf (lf) timing and when Mermentau was treated with quizalofop at 46 g ha^{-1} or more at PI.

Chapter 1. Introduction

Rice (*Oryza sativa* L.) is a cereal grain that is the staple food of nearly half of the world's population (Kubo and Purevdorj 2004). It is anticipated that global rice production must increase by more than 50% from levels in the 1990s to meet the world demand in 2025 (Peng and Yang 2003). Rice was originally domesticated in the Yangtze River basin of China between 8,200 to 13,500 years ago and was brought to the Carolina colonies of the present-day United States in 1865 (Dennis 1997; Smith and Dilday 2003; Sweeney and McCouch 2007; Vaughn et al. 2008). Rice is a valuable crop in the Southern United States with five of the six rice-producing states located in the region and over 1.05 million hectares (ha) planted in 2021. Louisiana is ranked second in the United States regarding rice production, accounting for 183,800 of the 1.05 million harvested hectares in the country (USDA NASS 2021b). The majority of the rice produced in the state is grown in the Northeast and Southwest regions with cultural management varying greatly between the two regions due to soil type, weed species, and environmental conditions (Bollich 1992).

In Louisiana, two different planting practices are commonly utilized for rice seeding (Harrell and Saichuk 2014). The predominant planting method in the state is dry seeding, which consists of mechanically drilling seed. The second method used is water-seeding, which consists of broadcasting pre-germinated rice seed into a shallow floodwater and this method accounted for 17% of total rice planted in the state in 2020 (Harrell 2020). Before the introduction of imidazoline-resistant (IR) (Clearfield™ Production System, BASF Corporation, Research Triangle Park NC) rice in 2002, an estimated 65 to 70% of Louisiana rice hectarage was water seeded (Eric Webster, Retired LSU Agricultural Center Extension Weed Scientist, personal communication, 2021). By using this planting method, a flood can be established earlier, creating

an unfavorable environment for weedy rice (*Oryza sativa* L.), and other weed seed germination (Dunand et al. 1985).

Weeds are a problematic pest in all crop production, including rice, due to heavy competition with cultivated crops for sunlight, water, and nutrients needed for optimum growth and yield (Smith 1988). Common weeds encountered in Louisiana rice production include broadleaf, annual and perennial grass, and sedge species. Broadleaf weed species that are commonly observed include alligatorweed [*Alternanthera philoxeroides* (Mart.) Grisb.], hemp sesbania [*Sesbania herbacea* (Mill) McVaugh], Indian jointvetch (*Aeschynomene indica* L.), and Texasweed [Caperonia palustris (L.) St. Hill]. Common annual grass species include Amazon sprangletop [*Leptochloa panicoides* (J. Presl) Hitchc.], barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv], broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R. D. Webster], junglerice (*Echinochloa colona* L.), Nealley's sprangletop (*Leptochloa nealleyi* Vasey), red rice (*Oryza sativa* L.), and spreading dayflower (*Commelina diffusa* Burm. F.) (Bergeron 2015a; 2015b; Webster 2011). Common perennial grass species include brook crowngrass (*Paspalum acuminatum* Raddi), creeping rivergrass [*Echinochloa polystachya* (Knuth) Hitch.], knotgrass (*Paspalum distichum* L.) and water paspalum (*Paspalum hydophilum* Henr.) (Bottoms et al. 2011; Griffin et al. 2008; Webster et al. 2007). Sedge weed species that are commonly observed include rice flatsedge (*Cyperus iria* L.) and yellow nutsedge (*Cyperus esculentus* L.).Using integrated weed management programs, growers control weeds using a variety of cultural, mechanical, and chemical methods to maximize economic returns and crop yields (Jordan and Sanders 1999). Rice producers frequently rely on herbicides to manage these weeds which can account for as much as 9% of production costs (Salassi 2014).

While all of the aforementioned weeds are problematic in rice production, the most troublesome is red rice. Red rice, often referred to as “weedy rice,” is a relative of cultivated rice and has several physiological characteristics that allow it to outcompete cultivated rice such as: a faster growth rate, greater maximum height, increased tillering capacity, and larger leaf area (Dodson 1898; Dodson 1900; Smith et al. 1977; Smith 1988; Vincenheller 1906). Dating back to the early 20th century, weedy rice has been reported as the most troublesome weed in rice production and has been identified as the biggest contributor to competition-based yield reduction to cultivated rice estimated as much as 80%.

Weedy rice is a conspecific weed of cultivated rice and refers to a complex of volunteer hybrids, outcrosses, and true red rice. Weedy rice was originally introduced as a contaminant of imported seed and has since evolved into widely divergent geographically specific populations (Constantin 1960; Noldin et al. 1999; Shivrain et al. 2010). These populations are all descendants of cultivated ancestors, specifically, *O. Sativa*, with the majority belonging to the *indica* subspecies group (Bevilacqua et al. 2015; Gross et al. 2009; Vaughan et al. 2001). In flooded rice culture, which is commonly used in the midsouth, nutrients and sunlight are the most limiting resources that red rice competes with cultivated rice and can result in a yield reduction of the cultivated rice crop (Burgos et al. 2006; Kwon et al. 1992). Furthermore, weedy rice can be especially problematic due to its ability to outcross with cultivated varieties and hybrids, enabling the inheritance of herbicide resistant traits and other superior phenotypic characteristics (Gealy et al. 2003).

This outcrossing occurs via hybridization of cultivated rice and weedy rice resulting in outcrosses that harbor several alleles present from cultivated rice parent plants and in the instance of IR rice outcrossing, that endow acetolactate synthase (ALS)-inhibitor herbicide

resistance (Singh et al. 2017). Throughout Louisiana several rice varieties and hybrids are grown resulting in populations of weedy rice that are highly diversified and segregated. For example, of all the long grain rice grown in Louisiana in 2020, 20% consisted of conventional varieties, 35% consisted of IR rice varieties, and 37% consisted of herbicide-resistant and herbicide non-resistant hybrids (Harrell 2020).

Arlyoxyphenoxypropionate herbicides inhibit the enzyme acetyl-Coenzyme-A carboxylase (ACCase). This enzyme is responsible for catalyzing the first committed step of fatty acid synthesis: the carboxylation of acetyl-CoA to malonyl-CoA (Burton et al. 1989, Focke and Lichtenthaler 1987). By inhibiting fatty acid synthesis, production of essential phospholipids crucial for membrane structure in new cells is halted. Herbicides in this group are particularly effective on grass species as broadleaf species possess inherent tolerance due to an insensitive ACCase enzyme (Stoltenberg et al. 1989). The Provisia™ production system (BASF Corporation, Raleigh NC) is a new herbicide-resistant rice technology that was first released in 2018. This system enables postemergence applications of quizalofop (Provisia™), an ACCase-inhibiting herbicide to be made directly over the top of the resistant rice (Guice et al. 2015).

Quizalofop is commonly used for the control of problematic annual and perennial grass weeds (Parsells 1985). Since quizalofop activity is primarily limited to grass weed species, herbicide mixtures are primarily used to aid in management of broadleaf and sedge weed species to avoid making multiple herbicide applications (Anonymous 2017b; Rustom et al. 2018). When herbicides are applied in a mixture, one of three responses can occur: antagonism, synergism, or a neutral response (Berenbaum 1981; Blackshaw et al. 2006; Blouin et al. 2004, 2010; Drury 1980; Fish et al. 2015, 2016; Hatzios and Penner 1985; Morse 1978; Nash 1981; Streibig et al. 1998). When the observed response of a herbicide mixture is greater than the expected responses

of the herbicides applied individually, the interaction is synergistic; when the observed response results in reduced control, the interaction is antagonistic (Colby 1967). If there is no difference between observed and expected control, the mixture is deemed neutral.

Quizalofop is labeled for the control of volunteer rice from the one- to four-leaf growth stage with a suggested minimum single application rate of 100 g ai ha^{-1}. Furthermore, the total use rate per season is 239 g ha^{-1}, which means growers are only allowed two applications per season (Anonymous 2017b). It has been suggested that the current two application limit should be extended to three applications using lower rates, and that adequate control of red rice and other grass weeds can be achieved past the four-leaf growth stage. If these lower rates provide adequate control of these weeds, the result could be the allocation of another quizalofop application if needed and consequently conserving more product for use later in the growing season should a weed problem arise. Furthermore, if adequate control can be achieved past the four-leaf growth stage, the utility of this herbicide for the control of weedy rice will be greatly enhanced and its window for use lengthened.

Most herbicides used in rice are applied aerially due to the flooded growing conditions which are difficult for ground applicators to maneuver through (Smith et al. 1977). While herbicide applications have proven to be effective, there is great risk of these herbicides moving off-target when applied and their subsequent deposition on susceptible crops. Frequently, the result of this phenomena is physical injury and a reduction in yield of the affected crop (Marrs et al. 1989). While continual efforts have been made in mitigating herbicide drift via the addition of a drift reducing agent (DRA) in herbicide applications and through the use of reduced drift nozzles that minimize the release of susceptible spray droplets less than 150 µm, drift events still occur and pose a serious threat to neighboring crops that are susceptible.

Herbicides can move off-target via three methods: particle drift, tank contamination, and vapor drift (Wolf 2000). Particle drift is the movement of spray droplets that can vary in diameter and occurs immediately after application. Spray droplets are categorized based on their diameter and range from extremely fine, less than 60 micrometers (µm) to ultra coarse, greater than 650 µm (ANSI/ASABI 2009). The size of spray droplets is the major determinant of the drift potential of herbicide sprays and its effect has been studied extensively. Spray droplet size is also affected by multiple factors including herbicide formulation, nozzle type, spray volume, and adjuvant usage (Mueller and Womac 1997; Whisenant et al. 1993; Yates et al. 1976). Spray droplet size can be easily modified by changing the operating pressure or by changing the nozzle orifice size. Spray droplets smaller than 150 µm are most susceptible to particle drift (Etheridge et al. 1999). However, there is a significant debate among applicators concerning optimal droplet size during application. While finer droplets result in greater coverage with increased off-target movement, coarser droplets allow more spray solution to deposit on the target but result in reduced coverage.

Tank contamination occurs when an applicator fails to properly clean a sprayer following a herbicide application and can result in herbicide residue that persists in applicator hoses, nozzles and tank lining (Boerboom 2004; Cundiff et al. 2017; Foster et al. 2018). Cundiff et al. (2017) evaluated the potential of five common hose types used in agricultural sprayers to sequester dicamba analyte following a dicamba application. Results indicated that hose types constructed of PVC polyurethane blend and synthetic rubber had increased retention of dicamba analyte compared to polyurethane blend hoses. Furthermore, through the use of scanning electron microscopy, it was evident that these hoses had imperfections within the inner hose

lining which ultimately lead to inner wall depletion and the resulting increase in sequestered dicamba analyte.

Vapor drift occurs when a herbicide is deposited on vegetation and then converted into a gaseous state from a liquid or solid state (Taylor and Spencer 1990). This form of drift is primarily a function of volatilization and is influenced by various abiotic factors like temperature and relative humidity (Egan and Mortenson 2012; Grover et al. 1972; Harper et al. 1983). An example of large-scale off-target movement in the agricultural landscape is the introduction of the glyphosate-resistant soybean [*Glycine max* (L.) Merr] cropping system (Padgette et al. 1995). While the introduction of this cropping system enabled broad-spectrum weed control with a single herbicide application, an unintended side-effect of its over-reliance was an increase in observed off-target movement of glyphosate applications onto neighboring susceptible vegetation (Reddy 2001). A specific example of this is the deposition of off-target glyphosate onto neighboring rice which resulted in an estimated 20,000 ha of injured or dead rice in Mississippi in 2006 (Wagner 2011). These herbicide-resistant varieties now constitute most of the soybean crop in the United States with the most recent estimate in 2010 equating to 83% of planted soybean hectarage (Bonny 2011). As a result of the increase in hectarage there are many areas throughout the Midsouth United States where soybean and rice are planted adjacent to one another.

Soybean is an oilseed legume grown for its many uses including animal feedstuff, biodiesel, edible oil, and other industrial uses (Ali 2010). Soybean cultivation is believed to have originated in Asia with the domestication of the annual wild soybean [*Glycine soja* (Sieb. And Zucc.)] and is estimated to have first been cultivated 3,600 to 4,500 years ago (Qiu and Chang 2010). The United States ranked second globally in 2020 soybean production with over 112

million tonnes produced (FAO STAT 2020). Soybean is the second most valuable crop in the United States with an estimated value of 46.1 billion dollars in 2020 (USDA NASS 2021d). Rice and soybean are commonly grown near one another in many areas throughout the Southern United States. As a result, areas throughout Arkansas, Louisiana, Mississippi, Missouri, and Texas are at risk of soybean intercepting off-target herbicide applications made to rice (Wilson et al. 2010). In many cases, herbicides that are used on one crop are not compatible with the other and can be injurious to unintended targets.

While all herbicides are susceptible to physical drift, some are also susceptible to vapor drift largely due to chemical formulation (Hatterman-Valenti et al. 1995). Many researchers have noted volatility of various dicamba salts (Behrens and Lueschen 1979; Sciumbato et al. 2004; Egan and Mortensen 2012; Strachan et al. 2010; Johnson et al. 2012). Previous research has shown that synthetic auxin herbicides like 2,4-dichlorophenoxy acetic acid (2,4-D) and dicamba are more susceptible to vapor drift than other herbicides. Results indicated 2,4-D formulated as an ester had volatilization approximately double amine salt-formulated 2,4-D (Hee and Sutherland 1974). These products have shown to cause yield losses as high as 33% when they deposit on susceptible vegetation (Egan et al. 2014). An example of differences among herbicide formulations suggests that the diglycolamine salt (DGA) dicamba formulation reduced volatility compared with the dimethylamine salt (DMA) formulation (Egan and Mortenson 2012). Along with herbicide formulations, herbicide volatility is also impacted by relative humidity and temperature at and/or shortly after the application is made. Low relative humidity coupled with a high temperature will result in more rapid evaporation of spray droplets (Grover et al. 1972).

Synthetic auxin herbicides mimic indole-3-acetic acid (IAA), a naturally occurring growth phytohormone within plants (Shaner 2014). Unlike other herbicides, the exact molecular

binding site and mechanism of action is not well defined. Auxins are the most abundant hormones in plants and their overarching effects on numerous plant development processes and role in a complex network of interactions with other phytohormones make them a prime candidate for use as a herbicide (Ross et al. 2002; Taiz and Zeiger 2002; Weidenhamer et al. 1989). When the concentration of auxin in a plant is too high, the result is uncontrolled cell growth and division and stem epinasty which negatively affects cell wall plasticity and subsequently inhibits growth (Shaner 2014).

Florpyrauxifen-benzyl (Loyant™, Corteva Agrisciences, Indianapolis IN) is a postemergence herbicide that was released for commercial use in the 2018 growing season. This herbicide is useful for the control of problematic broadleaf, grass, and sedge weeds in rice (Perry et al. 2015; Telo et al. 2018a, 2018b). Research has shown that a florpyrauxifen application of 30 g ai ha^{-1} resulted in greater than 90% control of barnyardgrass, yellow nutsedge, rice flatsedge, smallflower umbrellasedge (*Cyperus difformis* L.), hemp sesbania, Northern jointvetch, pitted morningglory (*Ipomoea lacunosa* L.), and palmer amaranth (*Amaranthus palmeri* S. Wats) 14 days after treatment (DAT) and greater than 75% control of fall panicum (*Panicum dichotomiflorum* Michx) and Nealley's sprangletop (Miller and Norsworthy 2017; Telo et al. 2018a).

Florpyrauxifen is a synthetic auxin and a member of the arylpicolinate chemical family. The chemical structure of florpyrauxifen is composed of a highly substituted 4-amino-pyridine ring (4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxyphenyl)-5-fluoro-pyridine-2-benzyl ester) that requires a hydrolysis reaction to be converted to its active acid form to achieve activity in target plants (Anonymous 2017a). Furthermore, research has shown that optimal absorption and translocation of florpyrauxifen is achieved with soil moisture at or above field capacity

(Miller and Norsworthy 2018a). As a result, the majority of florpyrauxifen applications are made aerially on flooded rice fields and capable of moving off-target. Symptomology of florpyrauxifen exposure to susceptible plants can vary depending on the rate of the applied herbicide. Low-rate exposure typically results in chlorosis of leaves and terminal buds, leaf cupping, and epinasty of stems and petioles. High-rate exposure will typically result in stem cracking, terminal death, and necrosis of leaves and other plant tissue (Soloman and Bradley 2014). Soybean has shown to be susceptible to florpyrauxifen resulting in physical injury and yield reductions up to 82% (Schwartz-Lazaro et al. 2017).

While research has shown that a soybean plant-back interval for a florpyrauxifen-treated rice field is relatively short (≤ 60 days), little research has been conducted on the effect of florpyrauxifen vapor and particle drift deposition on soybean (Miller et al. 2016). Preliminary research has shown that florpyrauxifen concentrations of 1.5 g ha^{-1} (1/20X) and 0.375 g ha^{-1} (1/80X) of the full labeled rate of 30 g ha^{-1} applied to soybean resulted in an 81 and 25% yield reduction, respectively (Schwartz-Lazaro et al. 2017). Florpyrauxifen injury symptomology is like other auxins with affected plants displaying stem cracking, leaf and petiole epinasty, and leaf chlorosis and necrosis (Miller and Norsworthy 2018b). Based on injury characteristics observed after florpyrauxifen application, there is reason to believe that soybean affected by florpyrauxifen will negatively impact yield. With many rice fields near or adjacent to soybean fields throughout the midsouth United States, it is imperative that the impact of florpyrauxifen drift is understood so producers can make informed management decisions in the event of drift and anticipate any crop damage and losses. Therefore, the objective of this study was to determine soybean tolerance to reduced rates of florpyrauxifen and quantify the effects on soybean.

While rice and soybeans are grown adjacent in many areas of the midsouth they also have similar planting windows. In Louisiana, the rice crop is planted between March 10 and May 5 while the soybean crop is planted between March 25 and May 10 (Harrell 2018). The proximity of these planting windows to one another increases the likelihood of off-target herbicide deposition from rice to soybean at an early vegetative growth stage. With the high risk of injury from an off-target application of florpyrauxifen, it is imperative that soybean tolerance to particle and vapor drift of florpyrauxifen is evaluated. With the impact on soybean plant growth and yield quantified, growers can make smart and informed decisions if a suspected drift event occurs.

With the introduction of these new technologies, it is important that their safety and utility be evaluated so that their niche in a rice production system can be realized. This research focus is on the drift potential of the new herbicide florpyrauxifen and an evaluation for the use of quizalofop at reduced rates to control red rice.

Chapter 2. Soybean Tolerance to Reduced Rates of Florpyrauxifen-benzyl

Introduction

Rice (*Oryza sativa* L.) is a cereal grain that is cultivated in over 95 countries worldwide and six states within the United States (Smith and Dilday 2003). Louisiana is second in rice production in the United States accounting for 183,800 of 1.05 million hectares (ha) harvested in 2021 (USDA NASS 2021b). Rice production in the state is mostly confined to the Northeast and Southwest regions of the state with Acadia, Jefferson Davis, and Vermillion parishes containing the most rice hectarage (USDA NASS 2021c).

Soybean [*Glycine max* (L.) Merr] is a leguminous annual that is grown in approximately 100 countries worldwide (FAO STAT 2020). Soybean is cultivated in 29 states within the United States with Louisiana accounting for 445,000 of 35.4 million ha planted in 2021 (USDA NASS 2021b). With more soybean hectarage present in the state compared with rice along with traditional rice-soybean crop rotations to preserve weed management technologies, there are many instances where these rice and soybean are cultivated in adjacent fields throughout Louisiana and the midsouth United States (Burgos et al. 2008).

With these two crops being cultivated in adjacent fields in many areas, there is an increased chance of off-target movement of applied herbicides between the two crops. Furthermore, the active planting window of rice and soybean has considerable overlap in the state of Louisiana. This creates many scenarios where vulnerable soybean plants at a young growth stage are at risk to exposure from herbicides being applied to neighboring rice. In many cases, herbicides that are used in one of these crops are not compatible with the other and therefore can be injurious to unintended targets. Synthetic auxin herbicides have shown to cause

yield losses as high as 33% when they deposit on susceptible vegetation such as non auxin-tolerant soybean (Egan et al. 2014).

In recent years, weed control in rice has primarily been achieved using acetolactate synthase (ALS) inhibiting herbicides. Through repeated use and overreliance of these herbicides, resistance has evolved in many weed species including: barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv], rice flatsedge (*Cyperus iria* L.), and yellow nutsedge (*Cyperus esculentus* L.) (Heap 2022; Riar et al. 2013a; Riar et al. 2015; Tehranchian et al. 2015). With the continual evolution of herbicide resistance in weed species a new herbicide site of action (SOA) is needed in rice production so that the portfolio of currently available herbicides can be used while eventual resistance evolution is prolonged.

In 2018, florpyrauxifen-benzyl (Loyant®, Corteva Agriscience, Indianapolis IN) was released as a new site of action in rice. This herbicide is effective for postemergence control of problematic broadleaf, grass, and sedge weeds in rice (Perry et al. 2015, Telo et al. 2018a; 2018b). Florpyrauxifen is a synthetic auxin and an analogue of the arylpicolinate chemical family. It is novel compared with other synthetic auxins due to its unique preferentiality for AFBF-Aux/IAA coreceptor F-Box proteins (Bell et al. 2015). The chemical structure of florpyrauxifen is composed of a highly substituted 4-amino-pyridine ring (4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxyphenyl)-5-fluoro-pyridine-2-benzyl ester) that requires a hydrolysis reaction to convert to the active acid of the molecule to achieve activity in target weeds (Anonymous 2017a). Furthermore, research has shown that optimal absorption and translocation of florpyrauxifen is achieved with soil moisture at or above field capacity (Miller and Norsworthy 2018a). Consequently, the half-life of florpyrauxifen in anerobic water of 2.65 days is considerably less compared with soil which is 55.30 days (US EPA 2017b). Consequently,

many applications are applied aerially, when the ground is saturated, which can increase the risk of off-target movement of this herbicide. Upon release in 2018, seven official complaints were recorded regarding suspected florpyrauxifen drift on soybean in Louisiana, indicating that this herbicide could pose a serious threat to soybean production (Bennett 2018).

When a herbicide is applied to a crop there is always a risk for off-target deposition of the applied herbicide. Herbicides can move off-target via three methods: vapor drift, particle drift, and tank contamination (Wolf 2000). Vapor drift or volatility is the result of a herbicide being converted from a solid or liquid chemical state to a gaseous state and occurs after spray droplets have reached their destination (Taylor and Spencer 1990). The volatility of a herbicide is largely dependent on its chemical formulation and is exacerbated by low relative humidity, high temperatures, and high wind speeds (Egan and Mortenson 2012; Grover et al. 1972; Harper et al. 1983). The herbicide in the gaseous form can then travel great distances and deposit on susceptible vegetation. Synthetic auxin herbicides are notorious for volatilization after application when conditions are favorable, with recurring examples of 2,4-dichlorophenoxy acetic acid (2,4-D) and dicamba vapor drift after being applied to soybean or cotton noted (US EPA 2017a).

Particle drift is the movement of physical spray droplets that occurs at the time of application. Particle drift is influenced by atmospheric stability, wind speed, spray boom height, applicator speed and nozzle selection (Hobson et al. 1993). Spray droplets are categorized based on their diameter and range from very fine to very coarse. The size of spray droplets is the major determinant of the drift potential of herbicide sprays and its effect has been studied extensively (Mueller and Womac 1997; Whisenant et al. 1993; Yates et al. 1976). Spray droplet size can be modified by changes in operating pressure or by changing the nozzle orifice size. Spray droplets

smaller than 150 micrometers (μm) are most susceptible to particle drift (Etheridge et al. 1999). All herbicides are susceptible to physical drift; however, herbicides with auxin activity have a history of vapor drift. This is especially true with 2,4-D and dicamba (Hatterman-Valenti et al. 1995; Hee and Sutherland 1974). Drift from herbicides with auxin activity like 2,4-D and dicamba is a current issue of major importance within the agricultural community that can result in serious crop damage (Riar et al. 2013b).

While research has shown that a soybean plant-back interval for a florpyrauxifen-treated rice field is relatively short (≤ 60 days), little research has been conducted on the effect of florpyrauxifen vapor and particle drift deposition on soybean (Miller et al. 2016). Preliminary research has shown that florpyrauxifen concentrations of 1.5 g ai ha^{-1} (1/20X) and 0.375 g ha^{-1} (1/80X) of the full labeled rate of 30 g ha^{-1} applied to soybean resulted in an 81 and 25% yield reduction, respectively (Schwartz-Lazaro et al. 2017). Florpyrauxifen injury symptomology is like other auxins with affected plants displaying stem cracking, leaf and petiole epinasty, and leaf chlorosis and necrosis (Miller and Norsworthy 2018b). Based on injury characteristics observed after florpyrauxifen application, there is reason to believe that soybean affected by florpyrauxifen will negatively impact yield. With many rice fields near or adjacent to soybean fields throughout the midsouth United States, it is imperative that the impact of florpyrauxifen drift is understood so producers can make informed management decisions in the event of drift and anticipate any crop damage and losses. Therefore, the objective of this study was to determine soybean tolerance to reduced rates of florpyrauxifen and quantify the effects on soybean.

Materials and Methods

The objective of this study was to evaluate vegetative and reproductive soybean tolerance to simulated florpyrauxifen drift and the impact on soybean growth and yield. Field Studies were established to evaluate soybean tolerance to reduced rates of florpyrauxifen when applied to soybean. Studies were conducted for three years at the Louisiana State University Agricultural Center (LSU Agricultural Center) H. Rouse Caffey Rice Research Station (RRS) (30.18°N, 92.35°W) near Crowley, Louisiana and the LSU Agricultural Center Dean Lee Research and Extension Center (DLREC) (31.18°N, 92.40°W) near Alexandria, Louisiana. The RRS location was on a Crowley silt loam with a pH of 5.1 and 1.66% organic matter (OM) and the DLREC location was a Coushatta silty clay loam with a pH of 6.8 and 2.25% OM. Following seedbed preparation, Delta Grow 49E20, an indeterminate glufosinate- and glyphosate-tolerant soybean was seeded at a density of 321,000 seeds ha^{-1} with plots at the DLREC location consisting of four, 76 cm spaced rows of 12.2 m in length and plots at the RRS location consisting of eight, 19 cm spaced rows of 5.2 m in length. The entire experimental area was kept pest-free throughout the growing season via timely fungicide (Price 2022), herbicide (Stephenson 2022), and insecticide (Davis and Brown 2021) applications based on LSU Agricultural Center recommendations.

The study was arranged as a randomized complete block design with an augmented two-factor, factorial treatment structure with four replications. Factor A consisted of soybean growth stage, where herbicide treatments were applied to V4 to V5 or R1 to R2 soybean to simulate a drift event occurring on soybeans in a vegetative or reproductive growth stage (Fehr and Caviness 1977). Factor B consisted of herbicide concentration. Herbicide drift solutions have been noted to vary in active ingredient concentration from 0.01 to 10% of the applied rate (Al-

Khatib and Peterson 1999). To represent the possible wide range of herbicide drift concentrations, florpyrauxifen was titrated using serial dilutions from the full-labeled rate of 29 g ai ha^{-1} plus 0.5% v/v of methylated seed oil adjuvant (Premium Methylated Spray Oil, Jimmy Sanders Inc., Cleveland, MS) to achieve specified concentrations of 0, 0.03, 0.12, 0.46, 1.84, and 7.36 g ha^{-1} or 0, 1/1024, 1/256, 1/64, 1/16, and 1/4, respectively, of the stock solution and applied to rice. Comparison herbicide treatments included a nontreated and two predetermined rates of dicamba at 0.56 g ae ha^{-1} found to cause significant soybean injury with no yield loss and a yield reduction rate of dicamba at 17.48 g ha^{-1} (Foster and Griffin 2018). Treatments were applied using a CO_2-pressurized backpack sprayer equipped with 110015 flat fan spray tips calibrated to deliver 140 L ha^{-1}. Visual estimates of soybean injury were recorded at 1, 7, 14, and 28 days after treatment (DAT), using a scale of 0 to 100%, where 0% = no injury and 100% = total plant death and plant heights (cm) were recorded at 7, 14, and 28 DAT (Frans et al. 1986). Plant heights were converted to a percent reduction relative to the nontreated at each application timing. At physiological maturity of the nontreated soybean, the center 1.5 m of each plot were machine harvested using a small plot combine and soybean yield (kg ha^{-1}) was adjusted to 13% moisture.

The effect of florpyrauxifen on soybean growth and yield was further evaluated by assessing the impact on individual soybean yield components including total branch length (TBL), branch number (BRN), node number (NN), reproductive node number (RNN), pod number (PN), and seed number (SN) (Board and Tan 1995). Individual components were recorded from four plants per plot and averaged for a whole plot value.

Visual injury and plant height reduction data were arranged as repeated measures and subjected to the GLIMMIX procedure of SAS (release 9.4, SAS Institute, Cary, NC). To account

for differing environmental effects between years and locations on herbicide treatments, replications (nested within treatments) and location and all interactions containing either of these effects were considered random (Carmer et al. 1989; Hager et al. 2003). Type III statistics were used to test possible fixed effect interactions and Tukey-Kramer's honestly significant difference test was used to separate means at the 5% probability level ($P \leq 0.05$) using the PLM procedure of SAS. To further characterize the effect of florpyrauxifen rate on soybean yield, the yields were converted to percent reductions relative to the nontreated and regressed over florpyrauxifen rate for each evaluated application timing. Parametric regression analysis was conducted using the easynls package within the ggplot2 package for data visualization in RStudio (version 1.3.1093, RStudio Inc., Boston MA). Each regression model was obtained via backward-elimination testing by exclusion of model terms not significant at the 10% probability level ($P \leq 0.1$). Following model term testing, the model that produced the greatest coefficient of determination was reported.

Results and Discussion

Injury, Height, and Yield Results. An application timing by herbicide rate by evaluation date interaction occurred for soybean visual injury (Table 2.1). Common symptomology observed for florpyrauxifen-treated soybean was consistent with previous research and included leaf and stem epinasty, reduced growth, callus tissue formation on stems and pod malformation (Miller and Norsworthy 2018c). These data indicate that total plant death was observed 14 and 28 DAT following an application of 7.36 g ha^{-1} of florpyrauxifen, 1/4x of the full rate, to soybean in a vegetative or reproductive growth stage. Additionally, these data show that soybean treated with florpyrauxifen are more susceptible to injury when in a vegetative growth stage compared with soybean treated at a reproductive growth stage. This is evident since the lowest concentration of

florpyrauxifen that resulted in significant injury was 0.12 g ha^{-1}, (1/256x) of the full rate, when applied to soybean at R1 to R2 compared with 0.03 g ha^{-1} (1/1024x), applied to V4 to V5 soybean.

Table 2.1. Soybean injury when treated with titrated rates of florpyrauxifen or dicamba 1, 7, 14, and 28 DAT at two different locations in 2018, 2019 and 2021.[a]

Timing[c]	Herbicide	Rate	Soybean visual injury[b] 1 DAT	7 DAT	14 DAT	28 DAT
		g ai/ae ha^{-1}	%			
V4-V5	Florpyrauxifen[d]	0.03	6 u-w	6 u-w	4 v-x	2 wx
		0.12	18 o-r	23 o	17 qr	15 q-t
		0.46	44 l	50 h-k	56 fg	35 m
		1.84	52 g-j	74 d	87 bc	89 b
		7.36	58 f	89 b	100 a	100 a
	Dicamba	0.56	7 u-w	15 q-t	20 o-q	13 r-t
		17.48	35 m	29 n	49 i-k	55 f-h
R1-R2	Florpyrauxifen	0.03	3 wx	3 wx	2 wx	2 wx
		0.12	11 s-u	17 qr	16 q-s	15 q-t
		0.46	45 kl	56 fg	49 i-k	47 j-l
		1.84	50 h-k	65 e	83 c	85 bc
		7.36	55 f-h	84 bc	100 a	100 a
	Dicamba	0.56	1 x	5 v-x	9 t-v	7 u-w
		17.48	23 o	19 o-q	31 mn	45 kl

[a]Means followed by a common letter do not significantly differ at $P \leq 0.05$ using Tukey-Kramer's HSD test.
[b]Visual injury was rated using a scale of 0 = no injury and 100 = complete plant death (Frans et al. 1986).
[c]Soybean growth stage defined by Fehr and Caviness (1977).
[d]Florpyrauxifen rates also included MSO titrated from 0.58 L ha^{-1}.

When comparing injury observed following florpyrauxifen treatments with dicamba treatments, it is evident that exposure to dicamba resulted in more pronounced injury with the 0.56 g ae ha^{-1} (1/1000x), applied at either timing compared with soybean treated with 0.12 g ha^{-1} (1/256x) of florpyrauxifen. Injury observed from soybean exposure to the dicamba comparison is similar to previous research conducted by Griffin et al. (2013) where 17.5 g ae ha^{-1} (1/32x) of dicamba applied to V4 and R1 soybean resulted in 44 and 31% injury at 14 DAT, respectively.

These data also highlight the high translocation of fast-acting synthetic auxins based on the observed injury 1 DAT which was 3 to 58% when soybean was treated with florpyrauxifen across all rates and injury was 1 to 35% when soybean was treated with dicamba. While it is well established that dicamba is highly mobile in phloem based on its low pKa of 1.87 and log K_{ow} of 0.29, the same can be assumed for florpyrauxifen transport based on the injury observed (Shaner 2014).

No interaction occurred for percent soybean plant height reductions; therefore, data were averaged across both application timings and all evaluation dates (Table 2.2). Data indicate that the greatest plant height reductions were observed when soybean was treated with 1.84 and 7.36 g ha^{-1} (1/16x and 1/4x), or more of florpyrauxifen. These results emphasize the importance of avoiding auxin drift to soybean as all evaluated rates of both herbicides resulted in decreased plant heights. Furthermore, these data also show that as herbicide rate increases, soybean plant height will decrease. Previous research conducted by Schwartz-Lazaro et al. (2017) shows similar plant height reductions of 37 and 21% observed following florpyrauxifen applications of 1.5 and 0.38 g ha^{-1} to V3 soybean, respectively.

An application timing by herbicide rate interaction occurred for soybean yield (Table 2.2). Results indicate that soybean yield decreases as florpyrauxifen concentration increases. Furthermore, when soybean were treated with florpyrauxifen at a rate of 7.36 g ha^{-1} (1/4x) at either timing, yield was 100% reduced from the nontreated yield of 3,550 kg ha^{-1} at the V4 to V5 timing and 3,500 kg ha^{-1} at the R1 to R2 timing.

The differential tolerance between soybean growth stages is likely attributed to many factors, particularly the extended vegetative growth period before flowering that occurs for later-maturing soybean cultivars in maturity groups IV and V, like the cultivar used in this study

(Moseley et al. 2022; Ritchie et al. 1994). This extended period enables greater recovery from herbicide-induced injury during early vegetative growth stages (Westgate 1999). As a result of this extended period, V4 to V5 soybean treated with florpyrauxifen concentrations of 0.46 g ha^{-1} or less were able to recover with no yield loss. This is important, as it is likely that the majority of florpyrauxifen drift events that occur will impact soybean in a vegetative growth stage due to the aforementioned overlapping planting windows of soybean and rice in Louisiana.

Table 2.2. Soybean percent plant height reductions when treated with titrated rates of florpyrauxifen or dicamba and yield at two different locations in 2018, 2019 and 2021.[a]

Timing[b]	Herbicide	Rate	Plant height reduction	Yield
		g ai/ae ha^{-1}	—— % ——	—— kg ha^{-1} ——
V4 to V5	Florpyrauxifen[c]	0	0 e	3550 a
		0.03	21 d	3370 a
		0.12	26 c	3520 a
		0.46	33 b	3170 ab
		1.84	39 a	1470 e
		7.36	43 a	0 f
	Dicamba	0.56	22 cd	3260 ab
		17.48	33 b	2560 cd
R1 to R2	Florpyrauxifen	0	-	3500 a
		0.03	-	3220 ab
		0.12	-	3200 ab
		0.46	-	2250 d
		1.84	-	440 f
		7.36	-	0 f
	Dicamba	0.56	-	3050 a-c
		17.48	-	2800 bc

[a]Means within columns followed by a common letter do not significantly differ at P≤ 0.05 using Tukey-Kramer's HSD test.
[b]Soybean growth stage defined by Fehr and Caviness (1977).
[c]Florpyrauxifen rates also included MSO titrated from 0.58 L ha^{-1}.

Yield Component Analysis. Individual soybean yield components were pooled across years and presented in Table 2.3. A herbicide rate main effect occurred for soybean branch number (BRN); therefore, data were averaged across application timings. Soybean treated with florpyrauxifen

rates of 1.84 g ha^{-1} (1/16x) and 7.36 g ha^{-1} (1/4x), resulted in reduced BRN of 2.2 and 0.9, respectively, while lower rates did not adversely impact branching. This is likely due to the formation of callus tissue on the main stem from injury sustained by applications of these higher rates which resulted in malformation of stems and nodes leading to decreased branching.

Table 2.3. Soybean yield component analysis when treated with florpyrauxifen or dicamba at theV4-V5 or R1-R2 growth stage[a].

			Individual soybean yield components[b]					
Timing[c]	Herbicide	Rate[d]	BRN	TBL	NN	RNN	PN	SN
		g ha^{-1}	— # —	— cm —	— # —	— # —	— # —	— # —
V4-V5	Florpyrauxifen[e]	0	3.2 a	148 a-e	27 a-c	21.0 ab	45 a	103 a
		0.03	3.2 a	155 a-d	26 bc	19.0 b	46 a	102 a
		0.12	3.5 a	170 a-c	27 a-c	20.9 ab	45 a	105 a
		0.46	3.3 a	181 a	24 c	19.3 ab	45 a	98 a
		1.84	2.2 b	76 g	11 e	6.8 de	23 c	49 d
		7.36	0.9 c	12 i	5 f	0 f	0 e	0 e
	Dicamba	0.56	3.5 a	175 ab	30 a	20.1 ab	43 ab	92 a
		17.48	3.3 a	132 d-f	14 e	9.5 d	37 b	75 b
R1-R2	Flopryrauxifen	0	-	143 b-e	27 a-c	20.2 ab	43 ab	99 a
		0.03	-	138 c-e	30 a	22.2 a	45 a	96 a
		0.12	-	136 c-e	27 a-c	18.0 b	41 ab	92 a
		0.46	-	100 fg	20 d	14.6 c	29 c	60 cd
		1.84	-	72 gh	14 e	7.1 de	11 d	5 e
		7.36	-	39 hi	12 e	5.0 e	7 d	0 e
	Dicamba	0.56	-	119 ef	26 bc	20.5 ab	42 ab	95 a
		17.48	-	80 g	19 d	14.8 c	37 b	73 bc

[a]Means within columns followed by a common letter do not significantly differ at P≤ 0.05 using Tukey-Kramer's HSD test.
[b]Yield component abbreviations: BRN = branch number; TBL = total branch length; NN = node number; RNN = reproductive node number; PN = pod number; SN = seed number.
[c]Soybean growth stage defined by Fehr and Caviness (1977).
[d]Florpyrauxifen rates expressed in g ai ha^{-1}; dicamba rates expressed in g ae ha^{-1}.
[e]Florpyrauxifen rates also included MSO titrated from 0.58 L ha^{-1}.

An application timing by herbicide rate interaction occurred for total branch length (TBL). Results indicated that TBL was reduced by applications of florpyrauxifen at both evaluated application timings compared with their respective nontreated comparisons. TBL was

greatest when treated with florpyrauxifen rates of 0.46 g ha^{-1} (1/64x) or less at the V4 to V5 application timing and 0.12 g ha^{-1} (1/256x) or less at the R1 to R2 timing. All other evaluated rates of florpyrauxifen resulted in decreases of TBL following application to soybean. When soybean were treated with dicamba, TBL was only decreased when treated with 17.48 g ha^{-1} at the R1 to R2 application timing. The decreases in TBL when treated with higher rates of florpyrauxifen and dicamba were likely due to severe epinasty that was observed when plants were treated with these rates. This epinasty resulted in shortened branch lengths and in severe cases, abscission of affected branches. These results again show that soybean was less affected regarding TBL when treated at the V4 to V5 application timing compared with the R1 to R2 timing as higher rates were required to reduced branching at the vegetative timing compared with the reproductive timing.

An application timing by herbicide rate interaction occurred for soybean node number (NN). Results indicated that soybean NN was similar to TBL when treated with florpyrauxifen where NN decreased as rate increased. NN was reduced compared with the nontreated for each application timing when soybean were treated with florpyrauxifen rates of 1.84 to 7.36 g ha^{-1} at the V4 to V5 timing and 0.46 to 7.36 g ha^{-1} at the R1 to R2 timing. Dicamba treated soybean resulted in reduced NN when treated with a rate of 17.48 g ha^{-1} for both application timings, while all other evaluated rates of dicamba and florpyrauxifen did not result in a reduction in NN. These reductions in NN are likely attributed to decreased plant height after exposure to herbicide applications which is reflected in the plant height data in (Table 2.2). All rates of florpyrauxifen and dicamba that reduced NN also reduced plant height at all evaluation dates. It is well accepted that soybean exposure to lethal concentrations of synthetic auxins such as dicamba results in a reduction of basal internode elongation and nodal stacking which in turn slows plant growth and

the development of new nodes on affected plants and is likely why NN was reduced in this study (Behrens and Lueschen 1979; Egan and Mortenson 2012).

An application timing by herbicide rate occurred for soybean reproductive node number (RNN). As with TBL and NN, as herbicide rate increased, RNN decreased. RNN was decreased when soybean were treated with florpyrauxifen rates of 1.84 to 7.36 g ha^{-1} at the V4 to V5 timing or rates of 0.46 to 7.36 g ha^{-1} at the R1 to R2 timing. Furthermore, similar TBL and NN, RNN was decreased when treated with 17.48 g ha^{-1} of dicamba at either application timing. These results are closely related to plot yield data (Table 2.2). All applied rates of florpyrauxifen and dicamba for both application timings which caused reduced RNN also resulted in decreased soybean yield. This reduction in yield is likely attributed to the reduction in RNN as they are responsible for pod and seed development.

An application timing by herbicide rate occurred for soybean pod number (PN). Similar to the aforementioned yield components, as herbicide rate increased PN decreased. PN were greatest when soybean was treated with florpyrauxifen rates of 0.03 to 0.46 g ha^{-1} at the V4 to V5 timing and 0.03 to 0.12 g ha^{-1} at the R1 to R2 timing while all other evaluated florpyrauxifen rates resulted in PN reductions. These observed PN reductions are attributed to the RNN reductions, as reproductive nodes are where pod formation occurs, hence why the same rates that reduced RNN also reduced PN.

An application timing by herbicide rate interaction occurred for soybean seed number (SN). As with other evaluated yield components SN decreased as herbicide rate increased. SN was not affected when florpyrauxifen rates of 0.03 to 0.46 g ha^{-1} were applied at the V4 to V5 timing and 0.03 to 0.12 g ha^{-1} were applied at the R1 to R2 timing while other florpyrauxifen rates resulted in SN decreases. Additionally, seed production was completely halted when

soybean was treated with a florpyrauxifen rate of 7.36 g ha^{-1} at either application timing compared with the nontreated soybean with 99 to 103 seeds $plant^{-1}$. Previous research has shown that out of two droplets of radiolabeled dicamba applied to adaxial surface of the fourth-uppermost trifoliate leaf, approximately 38 to 44% of the applied product was absorbed in soybean seed and pods (Zaccaro et al. 2020). Based on this previous research, it is likely that florpyrauxifen acts in a similar manner, accumulating in pods and seeds, thereby causing a resulting reduction in yield.

While higher concentrations of florpyrauxifen and dicamba applied to soybean negatively impacted yield components for both application timings, it is important to note that lower florpyrauxifen rates of 0.03 to 0.46 g ha^{-1} applied at the V4 to V5 timing and 0.03 to 0.12 g ha^{-1} applied at the R1 to R2 timing did not negatively affect the yield components evaluated. This indicates that soybean possess the ability to compensate and recover from herbicide-induced injury, and soybean more are tolerant to these lower concentrations of florpyrauxifen.

Regression Analysis. Regression of percentage soybean yield across florpyrauxifen applied rate resulted in a quadratic plateau trend for both evaluated timings (Table 2.4). Results indicate that the critical concentration which results in total yield loss was 4.44 g ha^{-1} when applied at the V4 to V5 timing and 2.57 g ha^{-1} when applied at the R1 to R2 timing. Based on these results, soybean is more tolerant to florpyrauxifen when treated at the vegetative timing compared with the reproductive timing. This differential response has been commonly observed with many herbicides, including dicamba, and is likely due to the inability to recover from damaged reproductive structures and apical meristems when treated during reproductive growth stages (Carpenter and Board 1997; Griffin et al. 2013; Wax et al. 1969).

Table 2.4. Coefficients of polynomial models for predicting percent soybean yield reduction response to concentration of florpyrauxifen (g ai ha^{-1}) applied at the V4-V5 or R1-R2 application timing.

		Polynomial model coefficients					
Timing[a]	Function[b]	*a*	*b*	*c*	R^2	Model *P*value	Critical Concentration[c]
V4-V5	QP	-6.236	48.134	-5.422	0.813	<.0001	4.44
R1-R2	QP	1.430	76.211	-14.823	0.927	<.0001	2.57

[a]Soybean growth stage defined by Fehr and Caviness (1977).
[b]QP = Quadratic-plateau. Model equation, $y \sim [a + b*x + c*I(x^2)]*(x <= -0.5*b/c) + \{a + I[-b^2/(4*c)]\}*(x > -0.5*b/c)$.
[c]Lowest florpyrauxifen rate in g ai ha^{-1} that results in a 100% yield reduction.

In summary, these data indicate that soybean response to florpyrauxifen treatment is largely dependent on the rate of florpyrauxifen and the growth stage of soybean at the time of application. Furthermore, these data highlight that soybean are more susceptible to florpyrauxifen particle drift as opposed to vapor drift as reported by Walker et al. (2021). Previous research has concluded that concentrations of herbicides that move off-target and deposit on susceptible vegetation can vary from 0.01 to 10% of the applied rate (Al-Khatib and Peterson 1999). Based on these results, soybean in this trial at the V4 to V5 growth stage are susceptible to off-target deposition of florpyrauxifen at a rate equaling 6.25% or 1.84 g ha^{-1} of the full rate which resulted in a 59% yield reduction to treated plants compared with nontreated plants. Furthermore, soybean at the R1 to R2 growth stage are also susceptible to off-target deposition of florpyrauxifen as treatment with rates equaling 6.25% or 1.84 g ha^{-1} and 1.5% or 0.46 g ha^{-1} of the full rate with 87 and 36% yield reductions, respectfully, for the treated plants compared to nontreated plants.

While the risk to the actively growing soybean crop from florpyrauxifen exposure has been detailed in this study, it is also important to note that subsequent progeny is also at risk (Miller and Norsworthy 2018c). This research has shown that soybean treated at the R4 and R5

growth stages with florpyrauxifen at a rate of 1.5 g ha^{-1} (1/20x) resulted in a 15 and 24% yield reduction to their subsequent progeny, respectively. Therefore, caution must be taken when applying this herbicide near susceptible crops such as soybean, especially if nearby fields are being cultivated for the purpose of marketable seed. Moreover, applicators should avoid applying this herbicide if soybean growing nearby are in a reproductive growth stage, as tolerance will be decreased, and negative impacts will be exacerbated. These results also provide a predictive tool in the regression analysis that can be used to estimate soybean yield loss based on suspected florpyrauxifen deposition and can possibly aid growers in decision-making regarding management options after a suspected off-target movement event.

Chapter 3. The Volatilization Potential of Florpyrauxifen-benzyl

Introduction

Weed management is an essential practice to maximize the productivity of agronomic crop production systems and has been complicated by the evolution of herbicide-resistant weeds. Herbicide-resistant weeds have caused herbicide options to be drastically reduced for certain crops, and the solution has been the creation of nonselective herbicide-resistant transgenic cultivars (Burnside 1992). These herbicide-resistant cultivars allow postemergence applications of the herbicides to be applied directly to crops with these technologies. While these technologies are useful in controlling a broad spectrum of weeds in one application, an unintended side effect of their overreliance is the increase in the potential of off-target movement following their application which can be injurious to nearby susceptible crops and reduce surrounding plant biodiversity (Bowe 2010).

Off-target movement of herbicides can occur via three methods, particle drift, vapor drift, and spray tank contamination (Wolf 2000). Particle or physical drift occurs at the time of application and is heavily influenced by wind speed, spray boom height, applicator speed, nozzle selection and atmospheric stability (Hobson et al. 1993). While most herbicide applications are susceptible to particle drift, some are also susceptible to vapor drift (Hatterman-Valenti et al. 1995; Staten 1946). Vapor drift occurs when a herbicide is deposited on vegetation and then converted into a gaseous state from a liquid or solid state (Taylor and Spencer 1990). This form of drift is primarily a function of volatilization and is influenced by various abiotic factors like temperature and relative humidity (Egan and Mortenson 2012; Grover et al. 1972; Harper et al. 1983).

An example of large-scale off-target movement in the agricultural landscape is the introduction of the glyphosate-resistant soybean [*Glycine max* (L.) Merr] cropping system (Padgette et al. 1995). While the introduction of this cropping system enabled broad-spectrum weed control with a single herbicide application, an unintended side-effect of its over-reliance was an increase in observed off-target movement of glyphosate applications onto neighboring susceptible vegetation (Reddy 2001). A specific example of this is the deposition of off-target glyphosate onto neighboring rice (*Oryza sativa* L.) which resulted in an estimated 20,000 ha of injured or dead rice in Mississippi in 2006 (Wagner 2011). These herbicide-resistant varieties now constitute most of the soybean crop in the United States with the most recent estimate in 2010 equating to 83% of planted soybean hectarage (Bonny 2011). As a result of the increase in acreage there are many areas throughout the Midsouth United States where soybean and rice are planted adjacent to one another.

In addition to soybean and rice crops being adjacent to one another they also share a similar planting window. In Louisiana, the rice crop and the soybean crop are planted in relatively the same time frame with averages between 2016 and 2020 of 92% of the rice and 64% of the soybean being planted by May 10 (USDA NASS 2021a) As a result, the rice crop is planted before the soybean crop and neighboring soybeans are in a young vegetative stage when the first postemergence herbicide applications are made to rice. The proximity of these planting windows to one another increases the likelihood of off-target herbicide deposition from rice to soybean.

Off-target movement of synthetic auxin herbicides has been a long-standing concern within the agricultural community (Riar et al. 2013a). These herbicides are members of the 4[(O)] HRAC/WSSA Herbicide Mechanism of Action Group that mimic indole-3-acetic acid (IAA), a

naturally occurring growth phytohormone (Shaner 2014). These herbicides include products such as 2,4-dichlorophenoxy acetic acid (2,4-D) and dicamba that are effective for broad-spectrum broadleaf weed control and as a result are injurious to a variety of crop and plant species (Mortensen et al. 2012). There have been many reported instances of these herbicides moving off-target via vapor drift when applied to cotton (*Gossypium hirsutum* L.) or soybean [*Glycine max* (L.) Merr] (US EPA 2017a).

Florpyrauxifen-benzyl (Loyant®, Corteva AgriSciences, Indianapolis, IN) is a new synthetic auxin herbicide that was released as a new site of action (SOA) for POST weed control in rice in 2018. This herbicide is useful for control of problematic broadleaf, grass, and sedge weeds in rice (Perry et al. 2015; Telo et al. 2018a, 2018b). It is novel compared with other synthetic auxins due to its unique preferentiality for AFBF-Aux/IAA coreceptor F-Box proteins (Bell et al. 2015). The chemical structure of florprauxifen is composed of a highly substituted 4-amino-pyridine ring (4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxyphenyl)-5-fluoro-pyridine-2-benzyl ester) that requires a hydrolysis reaction to convert to the active acid of the molecule to achieve activity in target weeds (Anonymous 2017a). Furthermore, research has shown that optimal absorption and translocation of florpyrauxifen is achieved with soil moisture at or above field capacity (Miller and Norsworthy 2018a). Consequently, the half-life of florpyrauxifen is 2.65 days in anaerobic water which is considerably less than in soil at 55.30 days (US EPA 2017b). Therefore, applications will be applied aerially due to the need for saturated soils to maximize activity, which will increase the risk of off-target movement of this herbicide. This risk was confirmed when the Arkansas Agriculture Department Plant Board received seven official complaints regarding off-target movement of florpyrauxifen when applied soon after introduction in 2018.

Previous research has shown that foliar-applied florpyrauxifen from 0.12 to 7.36 g ai ha^{-1} on soybean resulted in as great as 99% visual injury 28 days after treatment (DAT) with common symptomology including leaf and stem epinasty, stunting, and chlorosis and necrosis of leaves and stems (Walker et al. 2019). While it is assumed that the majority of off-target florpyrauxifen movement is attributed to particle drift, it is imperative to understand if vapor drift of florpyrauxifen is occurring when applied to a rice production system and if it can damage soybean. Additionally, with the vast difference in half-life among medias, it is also important to evaluate the effect of the media on the volatilization potential of florpyrauxifen.

Materials and Methods

The objective of this study was to determine the potential of florpyrauxifen to volatilize under field conditions when applied to rice and to evaluate the impact of field media on volatilization and the resulting impact on soybean. Field Studies were conducted in 2019 and 2020 at the LSU Agricultural Center H. Rouse Caffey Rice Research Station (RRS) near Crowley, Louisiana (30.18°N, 92.35°W) and the LSU Agricultural Center Dean Lee Research and Extension Center (DLREC) near Alexandria, Louisiana (31.18°N, 92.40°W). All field studies were conducted using conventional tillage production systems accompanied with typical agronomic production practices for fertility and crop maintenance. The RRS location was on a Crowley silt loam with a pH of 5.1 and 1.66% organic matter (OM) and the DLREC location was on a Coushatta silty clay loam with a pH of 6.8 and 2.25% OM. Following seedbed preparation, glufosinate-tolerant soybean was planted at a density of 321,000 seeds ha^{-1} in the form of two-row plots with dimensions of 1.5 by 15 m^2 oriented east to west. Plots were kept pest-free with routine applications of fungicides, herbicides, and insecticides as recommended by

LSU Agricultural Center disease (Price 2022), insect (Davis and Brown 2021), and weed (Stephenson 2022) pest management guides.

The study was arranged as a randomized complete block design with a two-factor, factorial treatment structure with three replications. Factor A was herbicide treatment. Treatments consisted of two herbicides: florpyrauxifen at a rate of 29 g ai ha^{-1}, and dicamba (Clairty® dicamba diglycolamine salt, BASF Corporation, Research Triangle Park NC) at a rate of 1121 g ae ha^{-1}, and a nontreated. Factor B was application media. To simulate herbicide applications made under different field conditions, three field medias were selected: bare soil, open water, and rice plant foliage. For the bare soil treatments, 29 cm by 50 cm by 3 cm flats were filled with Crowley silt loam soil and used at both locations. For the open water treatments, stainless steel trays with dimensions of 29 cm by 50 cm by 6 cm were filled with community water with a pH of 8.4. For the rice foliage treatments, flats with dimensions of 29 cm by 50 cm by 3 cm were filled with Crowley silt loam soil and seeded with CLXL-729 rice at a density of 80 kg ha^{-1}. Once the rice reached the four- to five-leaf (lf) growth stage, herbicide applications were made. For the bare soil and rice foliage treatment, flats were watered to field capacity prior to herbicide application. Herbicide applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} with an operating pressure of 276 kPa. The backpack sprayer consisted of a four-nozzle boom equipped with 110015 flat fan nozzles.

The plot layout is described in (Figure 3.1). Once soybean reached the R1 growth stage herbicide applications were made to the flats (Fehr and Caviness 1977). The plot center was used for treatment placement with 7.5 m of soybean on either side. Soybean served as a bioindicator as described in the seminal dicamba volatility paper by Behrens and Lueschen (1979) to observe herbicide volatility under field conditions. These treatments were made 800 m downwind of the

plot area and then transported to the area. Personnel who handled treated flats wore Tyvek® coveralls (DuPont™ Personal Protection, Wilmington DE) to prevent contamination of the plot area. A separate individual removed flats from the transport vehicle and placed them in the designated plot area. Two treated flats were then placed in the treatment area.

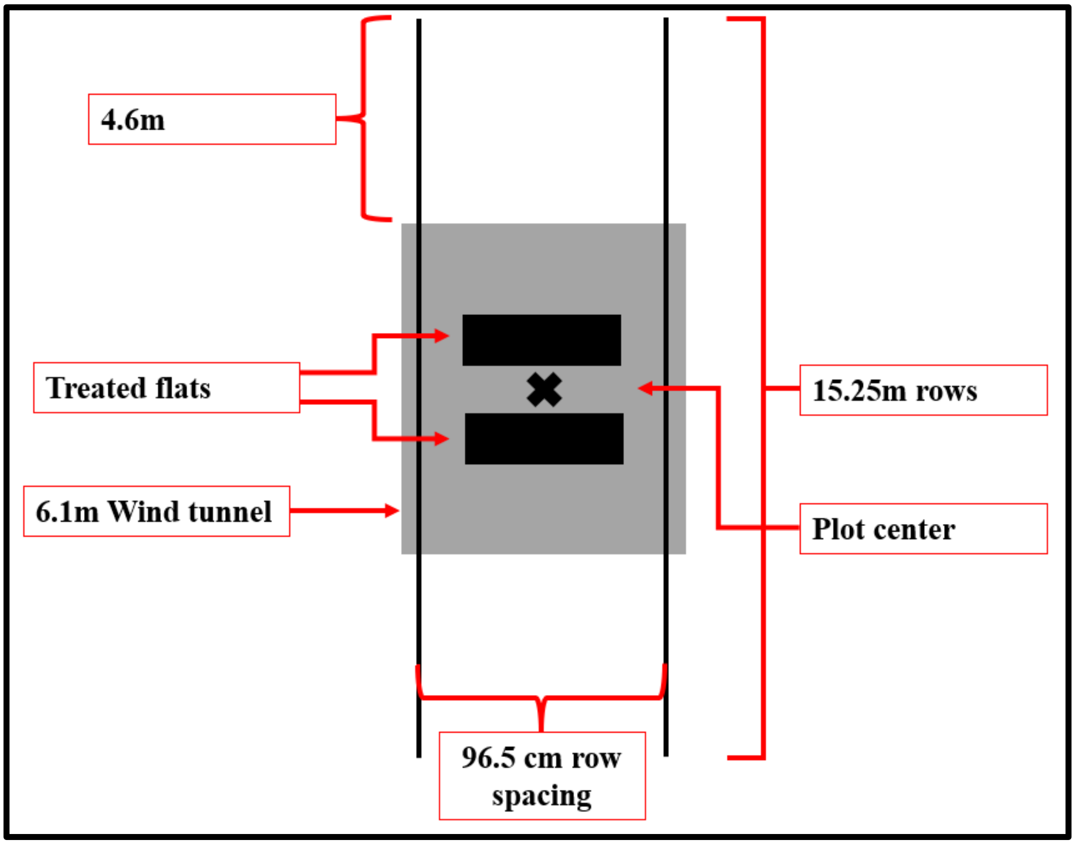

Figure 3.1. Visual diagram for bioindicator plot layout used at all locations in 2018 and 2019.

Wind tunnels with dimensions of 1 m by 6 m by 1.3 m were constructed with PVC hoop piping and three mil plastic sheeting (Barricade®, Next Generation Films Inc, Lexington OH) as a means for inducing favorable conditions for volatility to occur by raising the ambient temperature, directing wind, and decreasing relative humidity (Figure 3.2). Immediately after placement of treated flats in individual plots, a wind tunnel was place over the experimental unit. A WatchDog™ weather station (Spectrum Technologies Inc., Aurora IL) was placed in the center of the trial area to record ambient air temperature, soil temperature, relative humidity,

wind direction and speed for the duration of the trial (Table 3.1, Figures 3.3 and 3.4). The treated flats and wind tunnels were placed in the designated plot areas for 48 hours and then removed.

Figure 3.2 Treated flat and wind tunnel placement in plot area.

After wind tunnel and treated flat removal, weather data was obtained, and plant heights (cm) and soybean injury ratings were taken from the plot center to the plot edge in 31 cm increments in the direction of the predominant wind that occurred throughout the trial or >50% of trial duration. Visual estimates of soybean injury were recorded at 7, 14, and 28 days after treatment (DAT), using a scale of 0 to 100%, where 0% = no injury and 100% = total plant death (Frans et al. 1986). Plant heights were recorded at 7, 14, and 28 DAT and were expressed as a percent reduction from the nontreated.

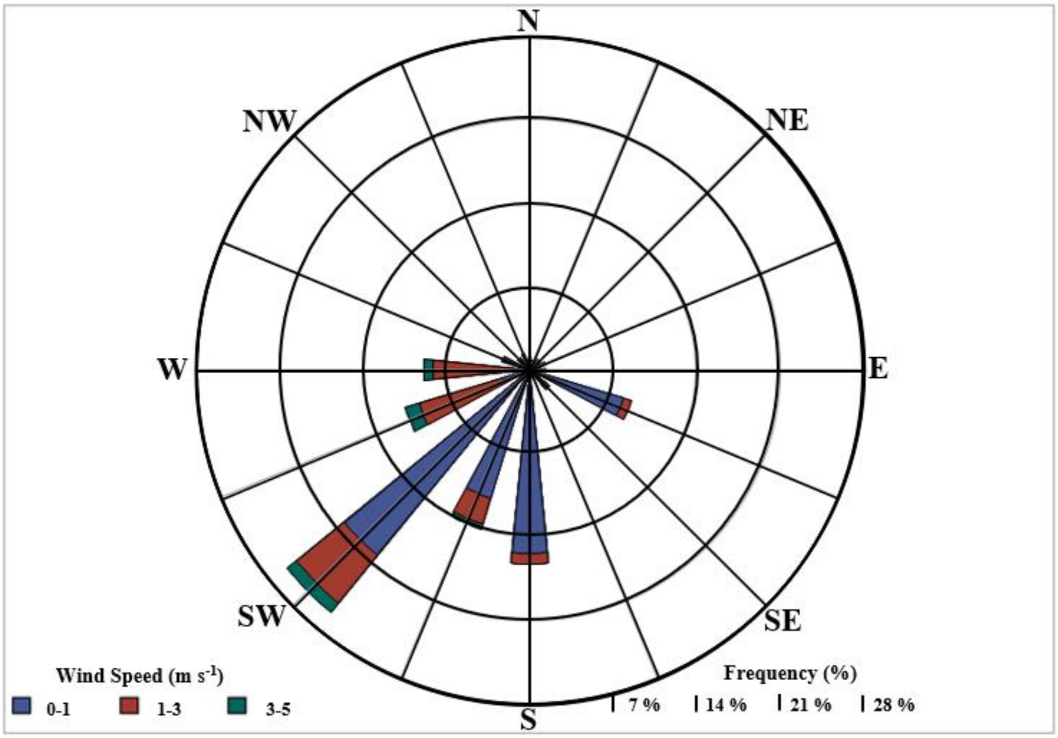

Figure 3.3 Wind rose diagram showcasing the frequency of recorded wind direction and speed during the 48-hour duration of the trial conducted in 2019 in Crowley, LA.

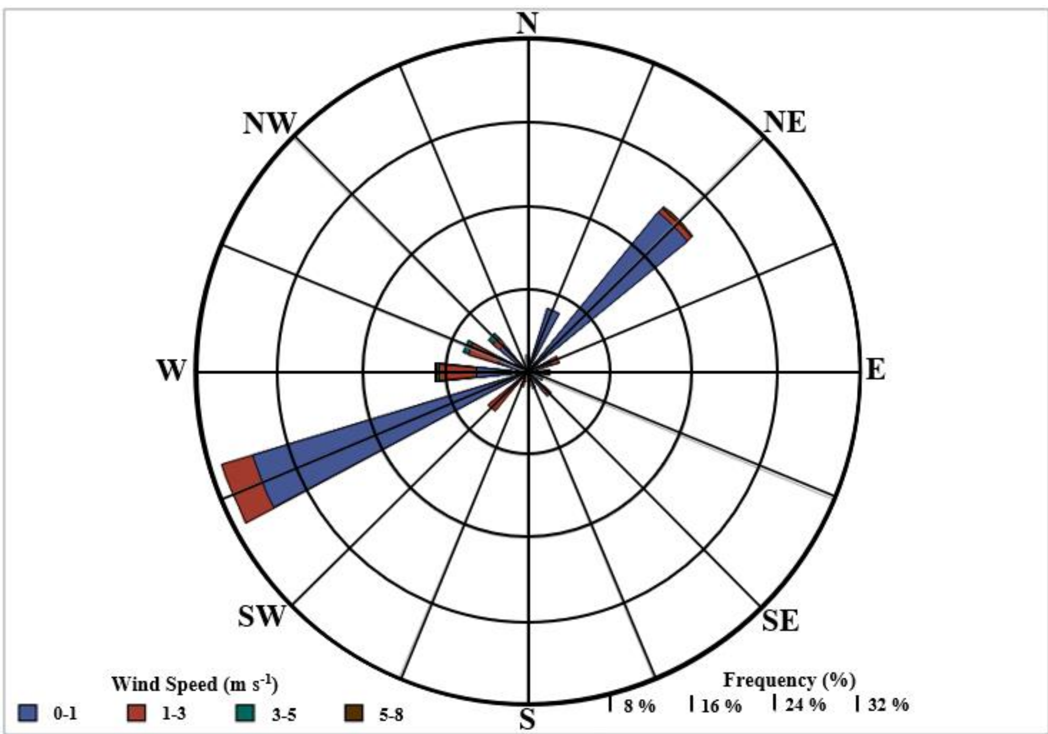

Figure 3.4 Wind rose diagram showcasing the frequency of recorded wind direction and speed during the 48-hour duration of the trial conducted in 2020 in Alexandria, LA.

Table 3.1. Meteorological data for trial duration in 2019 and 2020[bc]

Location	Application timing	Growth stage[a]	Temperature			Relative humidity	Wind speed
			Air	Soil Flat	Tunnel		
			C			%	m s^{-1}
Crowley, LA	8/8/2019; 10:00 AM	R1	28.6 ± 3.4	32.4 ± 4.1	30.9 ± 4.5	85.9 ± 13.2	0.8 ± 0.9
Alexandria, LA	8/4/2020; 10:00 AM	R1	26.9 ± 3.8	33.1 ± 9.1	30.5 ± 9.4	81.9 ± 14.9	1.5 ± 2.1

[a]Soybean growth stage defined by Fehr and Caviness (1977).
[b]Data are reported as mean ± standard deviation for the duration of each study (48 hours)
[c]Meteorological data was recorded at every minute (2,880 minutes) throughout each study

Data for all variables were subjected to the MIXED procedure in SAS 9.4 (SAS Institute Inc., Cary NC). Years and replications (nested in treatments), and all interactions containing these effects were considered random to account for environmental conditions having a possible effect on application media, herbicide treatments, and evaluation date (Carmer et al. 1989; Hager et al. 2003). Application media, herbicide treatment, and evaluation date were considered fixed effects. Type III statistics were used to test the possible interactions of fixed effects. Tukey-Kramer's honestly significant difference test ($p \leq 0.05$) was used for mean separation calculations. Mean separations and groupings were assigned using the SAS macro PDMIX800 (Saxton 1998).

Results and Discussion

Ambient air temperature averaged 29 C in 2019 and 27 C in 2020 for the duration of each trial, whereas relative humidity averaged 86% in 2019 and 82% in 2020 (Table 3.1). Wind speed was 0 to 5 m s^{-1} in 2019 and 0 to 8 m s^{-1} in 2020. A westerly wind was the prominent wind direction for both studies and as a result soybean visual injury and plant heights were confined to the east portions of plots (Figure 3.2 and 3.3).

A herbicide treatment by evaluation date interaction occurred for visual soybean injury (Table 3.2). Results indicated that field media had no impact on volatility of dicamba or florpyrauxifen with no differences observed between media or herbicide treatment by media combinations. Little to no injury occurred when soybean was exposed to florpyrauxifen applied on any of the evaluated field medias. Only soybean exposed to dicamba resulted in detectable injury at 7 and 14 DAT that averaged 1%. Average soybean plant height was not impacted, and there were no differences observed between herbicide treatment, field media, and evaluation date combinations (Table 3.2). Observed soybean injury for dicamba treatments was less than previous research conducted by Jones et al. (2019) where soybean injury was observed up to 9m from the treated flat following a 560 g ae ha^{-1} application of DGA dicamba. It is likely that the difference in results could largely be due to environmental conditions as the average wind speed for studies conducted by Jones et al. (2019) was 2 and 3 m s^{-1} compared to 0.8 and 1.5 m s^{1} observed in these studies.

Soybean response to florpyrauxifen and dicamba is displayed in Figures 3.5 and 3.6. Visual injury from volatilization of florpyrauxifen was only observed at 7 DAT up to 31 cm from the plot center. Visual injury from volatilization of dicamba was observed at 7 and 14 DAT up to 152 cm away from the plot center. These data indicate that the potential for volatilization of florpyrauxifen is lower than dicamba due to the observed distance.

In conclusion, the potential for florpyrauxifen volatilization after application is low. This result can be partially explained by the low vapor pressure of 0.032 megapascals (mPa) of florpyrauxifen compared with 1.67 mPa for dicamba (Lewis et al. 2016). To confirm these results, it would be useful to sample for airborne florpyrauxifen particulate using a polyurethane foam (PUF) air sampler to confirm volatilization. Furthermore, these results suggest that reported

cases of off-target movement of florpyrauxifen can more than likely be attributed to particle drift rather than vapor drift. Research conducted by Walker et al. (2019) to evaluate soybean tolerance to simulated florpyrauxifen particle drift supports this conclusion with an application of 0.03 g ai ha^{-1} of florpyrauxifen to R1 soybean resulting in a 15% yield reduction. Miller and Norsworthy (2018b) also highlighted the inherent sensitivity of soybean to florpyrauxifen compared with other field crops with treated soybean resulting in a 72% reduction in biomass compared with a 46% and 30% reduction in treated cotton and common sunflower (*Helianthus annuus* L.), respectively, while corn (*Zea mays* L.) and grain sorghum [*Sorghum bicolor* (L.) Moench] were not affected.

Table 3.2. Soybean visual injury and average plant height when treated with florpyrauxifen or dicamba averaged across study years and across field media.[a]

Herbicide[d]	Visual Injury (DAT)[bc] 7	14	28	Plant Height (DAT) 7	14	28
	%			cm		
Florpyrauxifen	0 b	0 b	0 b	53 ab	51 abc	51 abc
Dicamba	1 a	1 a	0 b	53 ab	51 abc	51 abc
Nontreated	0 b	0 b	0 b	55 a	54 ab	54 ab

[a]Means followed by a common letter do not significantly differ at P = 0.05 using Tukey’s honestly significant difference test.
[b]DAT = Days after treatment.
[c]Visual injury was measured on a scale of 0 = no injury and 100 = complete plant death based on visual symptomology (Franz et al. 1986).
[d]Florpyrauxifen application rate was 29 g ai ha^{-1} and dicamba application rate was 1121 g ae ha^{-1}.

Soybean response to florpyrauxifen and dicamba is displayed in Figures 3.5 and 3.6. Visual injury from volatilization of florpyrauxifen was only observed at 7 DAT up to 31 cm from the plot center. Visual injury from volatilization of dicamba was observed at 7 and 14 DAT up to 152 cm away from the plot center. These data indicate that the potential for volatilization of florpyrauxifen is lower than dicamba due to the observed distance.

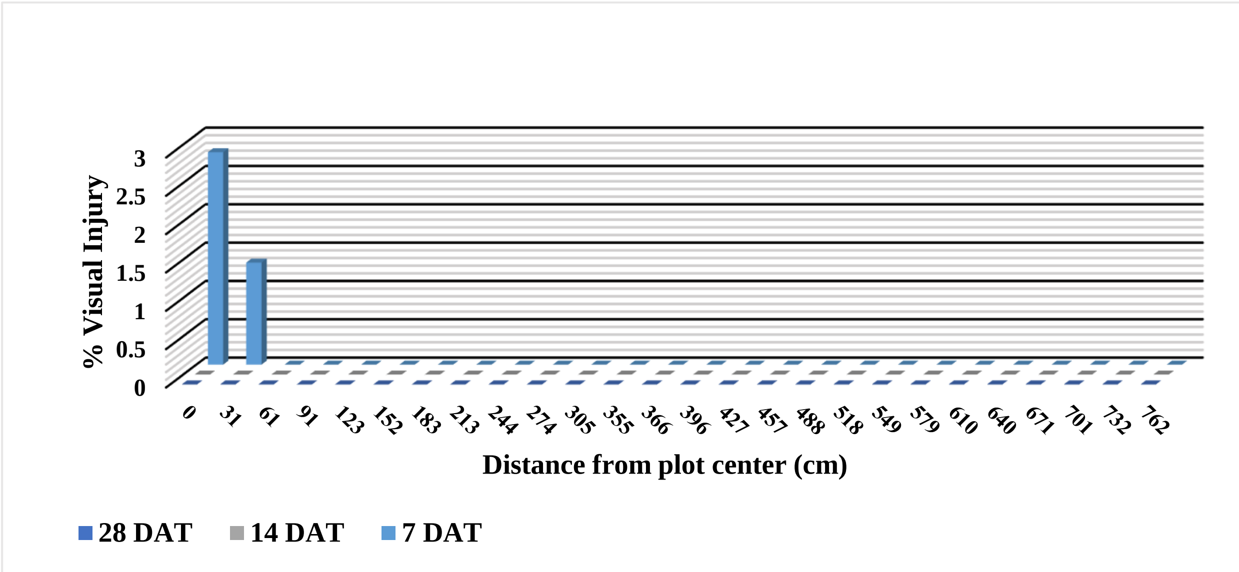

Figure 3.5. Average soybean response to volatilization of 29 g ai ha^{-1} of florpyrauxifen applied to bare soil, open water, or rice foliage by evaluation date for 2019 and 2020 trials.

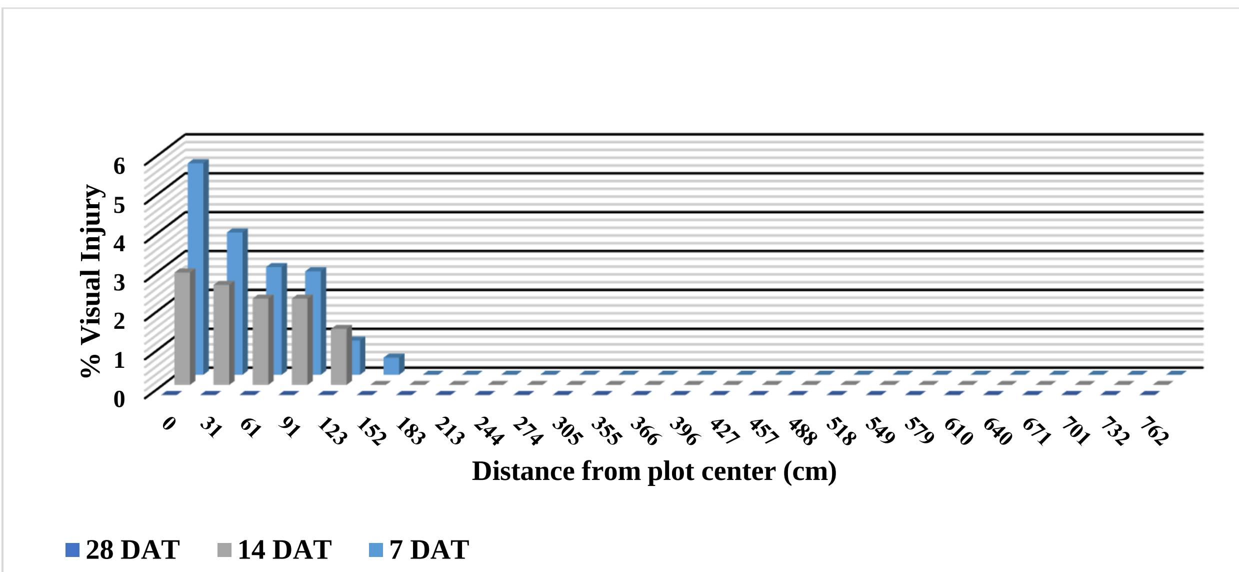

Figure 3.6. Average soybean response to volatilization of 1121 g ae ha^{-1} of DGA dicamba applied to bare soil, open water, or rice foliage by evaluation date for 2019 and 2020 studies.

While the potential for florpyrauxifen volatilization is low, it is still important for growers and applicators to be mindful of weather conditions when applying any herbicide. As previously stated, vapor drift is just one of many methods that herbicides can move off-target. Particle drift is still the largest occurrence of off-target movement and has the potential to occur

when applying any herbicide if weather conditions are favorable for off-target movement. These data provide insight to growers and applicators on what to expect if injury is observed near a field where an application of florpyrauxifen occurred. Based on these data, it can be assumed that if injury is observed, it is most likely due to particle drift that occurred at the time of application.

Chapter 4. Quizalofop Activity on Inbred Rice Lines and Hybrid Rice

Introduction

Rice (*Oryza sativa* L.) is a cereal grain staple in the diet for nearly half of the world's population and is cultivated in over 95 countries (Kubo and Purevdorj 2004; Smith and Dilday 2003). Louisiana ranks second in rice production in the United States accounting for 183,800 of 1.05 million ha harvested nationally in 2021 (USDA NASS 2021b). Rice production within the state occurs predominantly in the northeast and southwest regions which have differing soil types, weather conditions, and weed spectrums (Bollich 1992). As a result, many different cultivars and hybrids are planted throughout the state and various weed management programs are used so growers can maximize the utility of their given growing environment.

In Louisiana, two different planting practices are commonly utilized for rice seeding (Harrell and Saichuk 2014). The predominant planting method in the state is dry seeding, which consists of mechanically drilling seed. The second method used is water-seeding, which consists of broadcasting pre-germinated rice seed into a shallow floodwater and this method accounted for 17% of total rice planted in the state in 2020 (Harrell 2020). Before the introduction of imidazolinone-resistant (IR) (Clearfield™ Production System, BASF Corporation, Research Triangle Park NC) rice in 2002, an estimated 65 to 70% of Louisiana rice hectarage was water seeded (Eric Webster, Retired LSU Agricultural Center Extension Weed Scientist, personal communication). By using this planting method, a flood can be established earlier, creating an unfavorable environment for weedy rice (*Oryza sativa* L.), and other weed seed germination (Dunand et al. 1985).

Weed management is an essential practice in all crop production, including rice due to heavy competition with cultivated crops for sunlight, water, and nutrients needed for optimum

growth and yield (Smith 1998). Using integrated weed management programs, growers manage weeds using cultural, mechanical, and chemical methods to maximize economic returns and crop yields (Jordan and Sanders 1999). Common rice weeds encountered in Louisiana rice production include a variety of broadleaves and grasses. Common grass species include: barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], junglerice (*Echinochloa colona* L.), broadleaf signalgrass [*Urochloa platyphylla* (Nash) R.D. Webster], Amazon sprangletop [*Leptochloa panicoides* (J. Presl) Hitchc.], Nealley's sprangletop (*Leptochloa nealleyi* Vasey), and weedy rice (*Oryza sativa* L.) (Bergeron et al. 2015a, 2015b; Webster 2011). Rice producers frequently rely on chemical control via herbicide applications for the control of these weeds which can account for as much as 9% of production costs (Salassi 2014).

Weedy rice is a conspecific weed of cultivated rice and refers to a complex of volunteer hybrids, outcrosses, and true red rice. Weedy rice was originally introduced as a contaminant of imported seed and has since evolved into widely divergent geographically specific populations (Constantin 1960; Noldin et al. 1999; Shivrain et al. 2010). These populations are all descendants of cultivated ancestors, specifically, *O. Sativa*, with the majority belonging to the *indica* subspecies group (Bevilacqua et al. 2015; Gross et al. 2009; Vaughan et al. 2001). Weedy rice is a serious threat to all drill-seeded rice production due to its ability to outcompete cultivated rice for limiting resources such as nitrogen and sunlight which results in a yield reduction of cultivated rice (Burgos et al. 2006; Kwon et al. 1992; Smith 1988). Furthermore, weedy rice can be especially problematic due to its ability to outcross with cultivated varieties and hybrids, enabling the inheritance of herbicide resistant traits and other superior phenotypic characteristics (Gealy et al. 2003).

This outcrossing occurs via hybridization of cultivated rice and weedy rice resulting in outcrosses that harbor several alleles present from cultivated rice parent plants and in the instance of IR rice outcrossing, that endow acetolactate synthase (ALS)-inhibitor herbicide resistance (Singh et al. 2017). Throughout Louisiana several different rice varieties and hybrids are grown resulting in populations of weedy rice that are highly diversified and segregated. For example, out of all the long grain rice grown in Louisiana in 2020, 20% consisted of conventional varieties, 35% consisted of IR rice varieties, and 37% consisted of various herbicide-resistant hybrids (Harrell 2020).

To selectively control weedy rice along with other rice weeds, IR rice was commercially released in 2002. Herbicides in the imidazolinone family are members of the 2[(B)] mechanism of action group that inhibit the ALS enzyme, an essential enzyme that catalyzes the synthesis of branched-chain amino acids in plants (LaRossa and Schloss 1984; Shaner 2014). IR rice is a nontransgenic technology that was developed from an induced chemical mutation in the ALS enzyme complex of rice seed treated with ethyl methanesulfonate (Croughan 1994). This technology allows a postemergence (POST) application of imazamox (Beyond®, BASF Corporation, Research Triangle Park, NC), a preemergence (PRE) or POST application of imazethapyr (Newpath®, BASF Corporation, Research Triangle Park, NC), and a PRE or POST application a pre-package mixture of imazethapyr plus quinclorac (Clearpath®, BASF Corporation, Research Triangle Park, NC). While this technology was readily adopted and used successfully for weedy rice control, usage started to decline due to conferred IR in weedy rice (Burgos et al. 2008). The IR in weedy rice is believed to be transferred via natural outcrossing between cultivated rice and weedy rice (Gealy et al. 2003). With the increased weed pressure

from IR weedy rice and other rice weeds, a new technology was needed to obtain effective weed control.

The solution to controlling IR grass weeds was the development and release of quizalofop-resistant (QR) rice (Provisia® Rice System, BASF Corporation, Research Triangle Park, NC). Quizalofop-p-ethyl is a member of the aryloxyphenoxypropionate chemical family that inhibits acetyl-CoA carboxylase (ACCase), the enzyme responsible for catalyzing *de novo* fatty acid synthesis in plants (Burton et al. 1989; Shaner 2014). This technology allows POST applications of quizalofop (Provisia®, BASF Corporation, Research Triangle Park NC) to be applied directly over the top of the QR rice. Quizalofop is commonly used for the control of problematic annual and perennial grass weeds such as barnyardgrass, broadleaf signalgrass junglerice, sprangletop spp., and weedy rice (Anonymous 2017b; Parsells 1985). Concerning weedy rice, quizalofop is labeled for the control of plants at the one- to four-leaf (lf) growth stage with a suggested minimum single application rate of 100 to 139 g ai ha^{-1}. The total use rate per season is 239 g ha^{-1}, which means growers are only allowed two applications per season (Anonymous 2017b).

With the release of this new technology and the immense variety of cultivated rice lines, rice hybrids, and weed spectrums throughout Louisiana, it is important to evaluate the activity of quizalofop on different types of weedy rice present throughout Louisiana. If there are different levels of control for different types of weedy rice, then this information needs to be determined so growers can make a precise application without wasting product while still effectively managing weedy rice in their cultivated crop. Also, if a single application is not sufficient for certain types of weedy rice, then growers will be aware beforehand and can alter their management plan to be more aggressive. While this product is only labeled for the control of

one- to four-lf weedy rice it is important to evaluate the activity of quizalofop applied to larger, more mature weedy rice as well to determine if adequate control can be achieved later. If adequate control is achieved, the utility of the new QR rice system can be lengthened which allows growers more flexibility in the control of weedy rice.

Materials and Methods

The objective of this study was to evaluate the activity of quizalofop on two rice lines and a hybrid to mimic activity on different types of outcrossed weedy rice. To mimic different types of weedy rice across the state of Louisiana, two lines and a hybrid were selected, and activity was evaluated at a vegetative growth stage, two- to three-lf, and a reproductive growth stage, panicle initiation (PI). Field Studies were conducted in 2019 to 2021 at the LSU Agricultural Center H. Rouse Caffey Rice Research Station in Crowley, LA (30.17°N, 92.35°W; 30.18°N, 92.35°W) and the LSU Agricultural Center Northeast Louisiana Experiment Station (NERS) in St. Joseph, LA (31.95°N, 91.23°W). All field trials were conducted using conventional tillage production systems accompanied with typical agronomic production practices for fertility and crop maintenance (Harrell 2021). The Crowley location was on a Midland silty clay loam with a pH of 5.1 and 1.66% organic matter (OM) and a Crowley silt loam with a pH of 6.3 and 1.3% OM. The St. Joseph location was on a Sharkey clay with a pH of 7.8 and 1.3% OM.

Table 4.1. Seed and manufacturer information for all genotypes used in the study

Genotype	Technology	Seeding Rate[a]	Manufacturer
CL-111	IR line	78	LSU Agricultural Center, Baton Rouge, LA
CLXL-745	IR hybrid	45	RiceTec Inc., Alvin, TX
Mermentau	Conventional line	78	LSU Agricultural Center, Baton Rouge, LA

[a]Seeding rate is expressed in kg ha^{-1}.

The experimental design for the study was a randomized complete block with a three-factor factorial arrangement of treatments and three replications. Factor A consisted of rice type

which consisted of two inbred lines and a hybrid that were planted to represent or mimic common weedy rice types found in Louisiana rice fields (Table 4.1). Separate studies were conducted for each selection of rice and plot dimensions at the Crowley location were 3.0 by 9.1 m^2, consisting of 16, 19 cm spaced rows. Plot dimensions at the St. Joseph location were 1.5 by 5.2 m^2, consisting of 8, 19 cm spaced rows. Factor B consisted of quizalofop applied at six rates: 0, 23, 46, 69, 93, or 116 g ha^{-1}. Each rate of quizalofop included crop oil concentrate (COC) at 1% v/v (Agri-Dex®, Helena Agri-Enterprises LLC., Collierville, TN). Herbicides were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 94 L ha^{-1} and equipped with seven flat-fan 11001 nozzles spaced 48 cm apart. Factor C consisted of application timing, where herbicide applications were made at either the two- to three-leaf rice growth stage or at panicle initiation (PI). Water management for drill-seeded consisted of surface irrigation immediately after planting and approximately three weeks after planting and permanent flood establishment approximately 5 weeks after planting.

Plots were kept weed-free throughout the growing season via a delayed-PRE application of 1.12 kg ai ha^{-1} of pendimethalin (Prowl® H2O, BASF Corporation, Research Triangle Park, NC) plus 420 g ae ha^{-1} of quinclorac (Facet® L, BASF Corporation, Research Triangle Park, NC) 7 d after planting to allow imbibition of water into rice seed so that the risk of herbicide injury is reduced (Masson et al. 2001). Also, a POST application of 83 g ai ha^{-1} of a prepackage mixture containing halosulfuron plus prosulfuron (Gambit®, Gowan Company, Yuma, AZ) was applied when observed broadleaf and sedge weeds reached 5- to 7-cm in size.

Following treatment application, visual rice control evaluations were recorded at 7, 14, 21, and 28 days after treatment (DAT) as a percent with 0 = no control and 100 = complete plant death. Rice plant height was recorded from four plants in each plot measured from the base of

the plant at ground level to the tip of the extended panicle 7, 14, 21, and 28 DAT. Plots were harvested using a Wintersteiger® Quantum Pro combine (Wintersteiger Inc., Salt Lake City, UT) to determine rough rice yield and moisture was adjusted to 12%. Fresh aboveground plant biomass was also recorded at harvest by removing all plants within a 1 m length of a random row in each plot and expressed as a percent reduction from their respective non-treated control treatment.

Control and plant height data were arranged as repeated measures and subjected to the GLIMMIX procedure of SAS (release 9.4, SAS Institute, Cary, NC). To account for differing environmental effects between years and locations on herbicide treatments, replications (nested within treatments) and location and all interactions containing either of these effects were considered random (Carmer et al. 1989; Hager et al. 2003). Type III statistics were used to test possible fixed effect interactions and Tukey-Kramer's honestly significant difference test was used to separate means at the 5% probability level ($P \leq 0.05$) using the PLM procedure of SAS.

Results and Discussion

Clearfield Hybrid. An application timing by quizalofop rate by evaluation date interaction occurred for simulated CLXL-745 weedy rice control (Table 4.2). Common symptomology for affected plants included chlorotic and necrotic leaf and stem tissue and necrotic apical meristems on severely impacted plants. These data show that all evaluated rates of quizalofop applied at the two- to three-lf growth stage resulted in 90 to 99% control of CLXL-745 at 14, 21, and 28 DAT with no differences among rates or evaluation dates during this time frame. These data also suggest CLXL-745 is extremely sensitive to quizalofop at an early growth stage when treated with quizalofop at a rate of 23 g ha^{-1}. When comparing application time and quizalofop rate across rating dates it is apparent that quizalofop activity is delayed. This is most likely attributed

to characteristically low translocation of ACCase-inhibiting herbicides like quizalofop with previous research finding that only 14% of radiolabeled quizalofop applied to four-lf quackgrass [*Elymus repens* (L.) Gould] was recovered from plant shoots at 7 DAT (Tardiff and Leroux 1991). Control data observed is supported by previous research where 120 g ha^{-1} of quizalofop applied to CLXL-745 hybrid rice resulted in 97% control at 28 DAT (Rustom et al. 2018). Also, these data highlight that hybrid rice is substantially more tolerant to a quizalofop application at the PI application timing with all rates evaluated compared with CLXL 745 treated at the two- to three-lf growth stage application at 14, 21, and 28 DAT. These results are supported by previous research where conventional rice was treated with 336 g ha^{-1} of fenoxaprop, another ACCase-inhibiting herbicide, at the three- to four-lf and PI growth stages, which indicated that rice crop injury was reduced from 20% at the three- to four-lf timing to 8% at the PI timing. (Griffin and Baker 1990).

An application timing by quizalofop rate interaction occurred for hybrid rice percent plant height reductions based on the nontreated; therefore, data were averaged over evaluation dates (Table 4.2). Hybrid rice treated with 116 g ha^{-1} of quizalofop at the two- to three-lf timing resulted in plant height reductions greater than plants treated with 23, 46, and 69 g ha^{-1} of quizalofop at the same timing and all evaluated rates at the PI timing, further indicating the increased tolerance of larger plants.

An application timing by quizalofop rate interaction occurred for hybrid rice biomass reductions (Table 4.2). Biomass data indicates that a single application of 116 g ha^{-1} at either application timing and 46, 69, and 93 g ha^{-1} at the two- to three-lf timing resulted in similar biomass reductions of 90 to 99%. This indicates that while biomass was reduced at the PI timing with rice treated with 116 g ha^{-1}, the ability of hybrid rice plants to tiller and compensate for the

reduction in stand resulted in viable seed production and greater remaining biomass when treated with reduced rates of quizalofop (RJ Levy, Retired LSU Agricultural Center Extension Weed Scientist, personal communication).

Table 4.2. CLXL-745 control, plant height reduction, biomass reduction, and yield, when treated

		Visual Control DAT[abc]				Reduction[d]		
Timing	Quizalofop Rate	7	14	21	28	Height[e]	Biomass[f]	Yield
	g ai ha^{-1}	%						kg ha^{-1}
2- to 3-lf Leaf	116	87 b-d	99 a	99 a	99 a	61 a	94 a	190 e
	93	82 c-e	99 a	99 a	99 a	60 ab	93 a	290 e
	69	76 d-f	98 ab	99 a	97 ab	55 bc	91 ab	420 e
	46	71 e-g	97 ab	98 ab	96 ab	53 c	90 ab	750 de
	23	56 hi	90 a-c	92 a-c	91 a-c	29 d	71 c	2590 c
	0	-	-	-	-	-	-	5820 ab
PI	116	34 j-l	65 f-h	71 e-g	77 d-f	26 de	93 a	840 d
	93	28 k-m	56 hi	65 f-h	68 f-h	22 ef	86 b	1300 d
	69	22 l-n	47 ij	61 gh	55 hi	19 ef	68 c	2980 c
	46	15 m-o	33 kl	40 jk	37 jk	18 f	47 d	3160 c
	23	3 o	15 m-o	14 no	3 o	4 g	18 e	5150 b
	0	-	-	-	-	-	-	6370 a

[a] Means followed by a common letter at any rating date do not significantly differ at $P \leq 0.05$ using Tukey's honestly significant different test.
[b] Control was measured using a scale of 0 = no control and 100 = complete plant death based on visual symptoms.
[c] DAT = Days After Treatment.
[d] Plant height and biomass reduction were expressed as a percent reduction from the nontreated for each application timing. Means followed by a common letter within columns do not significantly differ at $P \leq 0.05$ using Tukey's honestly significant different test.
[e] Average plant height for nontreated was 34 cm for the two- to three-leaf application timing and 102 cm for the panicle initiation timing.
[f] Average biomass for the nontreated was 2385 g for the two- to three-leaf application timing and 3165 g for the panicle initiation timing.

An application timing by quizalofop rate interaction occurred for hybrid rice yield (Table 4.2). Rough rice yield observed for treated hybrid rice was 190 to 2590 kg ha^{-1} when CLXL-745 was treated at the two- to three-lf application timing and 840 to 5150 kg ha^{-1} at the PI application timing for treated plants. Yield data shows that the greatest yield reductions were observed when rice was treated at the two- to three-lf growth stage with quizalofop rates of 46, 69, 93, and 116 g

ha^{-1}. Therefore, applying 46 g ha^{-1} of quizalofop results in control, and yield that did not differ from rice treated with the 116 g ha^{-1} rate. These data indicate that a reduced rate of quizalofop may be an option as an early season application and would allow for more product to be applied later in the growing season. Yield data also indicates the resiliency of hybrid rice to continue seed production when impacted by quizalofop. If hybrid rice plants are not controlled, they can possibly disperse viable seed which are well documented to remain dormant for more than twice the time of inbred lines and can potentially infest a cultivated crop the following years (Singh et al. 2016). This increased seed production can most likely be attributed to tillering and regrowth that occurred after quizalofop application on plants that were not completely controlled (Lancaster et al. 2018). If these plants can produce viable tillers, they can then accumulate more nutrients needed to produce viable seed. Furthermore, in the case of weedy rice, if this seed is able to disperse and remain dormant during a subsequent herbicide application emergence of new weedy rice could occur.

These data further highlight the importance of controlling weedy rice early and pose the question of how effective a sequential application would be at the PI timing. If a sequential application of 116 to 174 g ha^{-1} is made following a 46 g ha^{-1} application to PI hybrid rice provides complete control before viable seed is produced and able to disperse, then the utility of quizalofop on hybrid rice could be expanded.

By using sequential applications, seed-head production can be suppressed, and later germinating plants can be prevented, providing a longer weed-free period and increasing cultivated rice yield potential. Prior research conducted by Askew et al. (2000) has shown that graminicides such as quizalofop and clethodim applied at 70 and 110 g ha^{-1}, respectively, to red rice at the two- to three-tiller and boot growth stages resulted in red rice seed head suppression of 93 to 98% of the

nontreated. These results further illustrate that early control is essential and most directly correlates to decreasing seed production.

Clearfield Inbred Line. An application timing by quizalofop rate by evaluation date interaction occurred for simulated CL-111 weedy rice control (Table 4.3). Results indicate that all evaluated rates of quizalofop applied at the two- to three-lf growth stage resulted in 90 to 99% visual control of CL-111 at 14, 21, and 28 DAT with no differences among rates or evaluation dates during this time frame, similar to CLXL-745 control data (Table 4.2). Similar to CLXL-745, CL-111 control was maximized at the two- to three-leaf timing with all evaluated rates of quizalofop resulting in greater control at 14, 21, and 28 DAT compared to being applied at the panicle initiation growth stage, thereby highlighting the increased sensitivity of CL-111 to quizalofop at a young vegetative growth stage.

An application timing by quizalofop rate interaction occurred for CL-111 percent plant height reductions based on the nontreated; therefore, data were averaged over evaluation dates (Table 4.3). Data indicate that the greatest CL-111 plant height reductions occurred when treated with 46 g ha^{-1} or more of quizalofop applied at the two- to three-lf growth stage. Plant height data also indicates that reductions were greater when applied at the two-to three-lf growth stage compared with plants treated at PI. Furthermore, these data indicate that CL-111 is more tolerant to quizalofop when the initial application is delayed to PI. This increased tolerance is likely due to the increased size of rice plants when treated at PI. Previous research has shown that graminicides are less effective when applied to larger plants with more foliage in a reproductive growth stage compared to a vegetative growth (Clay et al. 2006). This differential tolerance is likely due to the decreased growth rate of rice plants when in a reproductive growth stage and is

evidenced by the quadratic relationship between rice plant height and days after planting described by Fageria (2007).

An application timing by quizalofop rate interaction occurred for CL-111 rice biomass reductions (Table 4.3). Biomass data indicates that an application of 93 g ha^{-1} applied at the two- to three-lf growth stage or 116 g ha^{-1} at either growth stage resulted in the biomass reduction of 91 to 95%. Compared with hybrid rice (Table 4.2), CL-111 was more tolerant regarding plant biomass with a greater rate of quizalofop required to maximize biomass reduction (Table 4.2). However, similar to hybrid rice, lower rates of quizalofop did not maximize biomass reduction, indicating that plants were able to compensate as a result of regrowth and tillering after application. Compared with the nontreated, data indicate that quizalofop effectively reduces CL-111 biomass with all evaluated rate and timing combinations resulting in a biomass reduction.

An application timing by quizalofop rate interaction occurred for CL-111 yield (Table 4.3). Rough rice yield observed for treated CL-111 rice was 0 to 2340 kg ha^{-1} when applied at the two- to three-lf growth stage and 0 to 3550 kg ha^{-1} when applied at the panicle initiation growth stage. Results indicate reduced rates of 69 or 93 g ha^{-1} of quizalofop applied at either application timing resulted in CL-111 yield reductions similar to that of the labeled rate of 116 g ha^{-1}. Furthermore, it is evident that CL-111 is susceptible to quizalofop and yield can be most effectively reduced when applying 69 g ha^{-1} or more of quizalofop at the two- to three-lf or PI growth stage. Compared with hybrid rice (Table 4.2) this herbicide-resistant inbred line appears to be more susceptible which is likely due to the increased vigor of hybrid rice with previous research noting that regeneration rates of hybrid rice were approximately 50% greater than that of inbred rice (Chen et al. 2018).

Table 4.3. CL-111 control, plant height reduction, biomass reduction, and yield, when treated with quizalofop at the two- to three-leaf (lf) or panicle initiation (P.I.) growth stage.

		Visual Control DAT[abc]				Reduction[d]		
Timing	Quizalofop Rate	7	14	21	28	Height[e]	Biomass[f]	Yield
	– g ai ha^{-1} –	%						kg ha^{-1}
2- to 3-lf Leaf	116	87 bc	99 a	99 a	99 a	60 a	95 a	0 f
	93	82 cd	99 a	99 a	99 a	57 a	93 ab	0 f
	69	76 c-e	98 a	98 a	97 a	57 a	85 c	570 ef
	46	71 c-f	97 a	98 a	96 ab	56 a	78 d	770 e
	23	56 f-h	90 ab	92 ab	91 ab	44 b	44 g	2340 c
	0	-	-	-	-	-	-	5850 a
PI	116	32 i-l	62 ef	69 d-f	75 c-e	21 c	91 ab	0 f
	93	26 j-m	54 gh	62 ef	66 ef	20 c	89 bc	190 ef
	69	20 k-n	45 gh	59 fg	53 gh	17 c	73 e	470 ef
	46	12 l-o	31 j-l	38 ij	35 i-k	15 c	64 f	1560 d
	23	1 no	13 l-n	12 l-o	1 no	4 d	48 g	3550 b
	0	-	-	-	-	-	-	5830 a

[a] Means followed by a common letter at any rating date do not significantly differ at $P \leq 0.05$ using Tukey's honestly significant different test.
[b] Control was measured using a scale of 0 = no control and 100 = complete plant death based on visual symptoms.
[c] DAT = Days After Treatment.
[d] Plant height and biomass reduction were expressed as a percent reduction from the nontreated for each application timing. Means followed by a common letter within columns do not significantly differ at $P \leq 0.05$ using Tukey's honestly significant different test.
[e] Average plant height for nontreated was 33 cm for the two- to three-leaf application timing and 95 cm for the panicle initiation timing.
[f] Average biomass for the nontreated was 2080 g for the two- to three-leaf application timing and 2800 g for the panicle initiation timing.

Conventional Inbred Line. An application timing by quizalofop rate by evaluation date interaction occurred for simulated Mermentau weedy rice control (Table 4.4). Results indicate that quizalofop applied at 46 to 116 g ha^{-1} to rice at the two- to three-lf growth stage resulted in 98 to 99% control at 14, 21, and 28 DAT. These findings are similar to those reported by Camacho et al. (2018) who observed complete mortality of two- to three-lf Mermentau rice plants when treated with a foliar solution of 2 mg L^{-1} of quizalofop. Mermentau treated with the same rates of quizalofop at PI resulted in control of 20 to 80%, which was reduced compared

with control of Mermentau treated at the earlier growth stage. These results indicate that maximum Mermentau control is achieved when applying 46 to 116 g ha^{-1} of quizalofop at the two- to three-lf timing, and that initial control is delayed when applying quizalofop at the two- to three-lf growth stage. Furthermore, these data indicate that Mermentau rice possesses increased tolerance to quizalofop at the PI growth stage, reiterating the importance of early management to avoid sustained competition with cultivated rice.

As with CLXL-745 and CL-111 rice, an application timing by quizalofop rate interaction occurred for Mermentau height reductions as percent of the nontreated; therefore, data were averaged over evaluation dates (Table 4.4). Plant height reductions of 31 to 64% occurred following a quizalofop application at the two- to three-lf growth stage and reductions of 1 to 20% occurred following a quizalofop application at the PI growth stage. These results show that maximum plant height reductions occurred when quizalofop was applied at the two- to three-lf timing like CLXL-745 and CL-111. Similar to other evaluated rice types, as quizalofop rate increases, rice plant height reductions also increase.

An application timing by quizalofop rate interaction occurred for Mermentau percent biomass reductions (Table 4.4). Results indicate that the greatest observed Mermentau biomass reductions occurred when a quizalofop rate of 69 g ha^{-1} or more was applied at the two- to three-lf growth stage resulting in a 90 to 93% reduction. Unlike previously evaluated herbicide-resistant hybrid and inbred rice, conventional inbred rice biomass reduction was not maximized by any evaluated rate at the panicle initiation timing. This can possibly be attributed to the agronomic characteristics of Mermentau rice, which was developed as an early maturing, short-statured line, thereby resulting in plants with less overall biomass compared with the other evaluated hybrid and herbicide-resistant line (Oard et al. 2014).

Table 4.4. Mermentau control, plant height reduction, biomass reduction, and yield, when treated with quizalofop at the two- to three-leaf (lf) or panicle initiation (P.I.) growth stage.

		Visual Control DAT[abc]				Reduction[d]		
Timing	Quizalofop Rate	7	14	21	28	Height[e]	Biomass[f]	Yield
	– g ai ha^{-1} –	%						kg ha^{-1}
2- to 3-lf Leaf	116	71 b-d	99 a	99 a	99 a	62 ab	93 a	0 f
	93	65 b-d	99 a	99 a	99 a	64 a	91 a	0 f
	69	59 c-f	98 a	99 a	98 a	64 a	90 a	0 f
	46	48 d-g	98 a	99 a	98 a	57 b	85 b	0 f
	23	38 e-g	68 b-d	75 b-d	84 b	31 c	64 d	310 f
	0	-	-	-	-	-	-	5920 a
PI	116	13 e-i	48 d-g	65 b-d	80 bc	20 d	78 c	360 f
	93	10 e-i	40 e-g	45 e-g	60 c-e	18 de	66 d	790 e
	69	5 g-i	30 e-h	30 e-h	30 e-h	8 ef	59 e	1510 d
	46	5 g-i	23 e-h	20 e-h	10 e-i	8 ef	38 f	2460 c
	23	5 g-i	5 g-i	0 g-i	0 g-i	1 f	30 g	3470 b
	0	-	-	-	-	-	-	6190 a

[a] Means followed by a common letter at any rating date do not significantly differ at $P \leq 0.05$ using Tukey's honestly significant different test.
[b] Control was measured using a scale of 0 = no control and 100 = complete plant death based on visual symptoms.
[c] DAT = Days After Treatment.
[d] Plant height and biomass reduction were expressed as a percent reduction from the nontreated for each application timing. Means followed by a common letter within columns do not significantly differ at $P \leq 0.05$ using Tukey's honestly significant different test.
[e] Average plant height for nontreated was 37 cm for the two- to three-leaf application timing and 91 cm for the panicle initiation timing.
[f] Average biomass for the nontreated was 1900 g for the two- to three-leaf application timing and 2500 g for the panicle initiation timing.

An application timing by quizalofop rate interaction occurred for Mermentau rice yield (Table 4.4). Rough rice yield observed for treated Mermentau rice was 0 to 310 kg ha^{-1} following a quizalofop application at the two- to three-lf growth stage and 360 to 3470 kg ha^{-1} following a quizalofop application at the panicle initiation growth stage. Yield data shows that the greatest Mermentau yield reductions were observed when treated with 23 to 116 g ha^{-1} at the two- to three-lf timing and 116 g ha^{-1} at the PI timing. Yield data indicates that while biomass and plant height reductions were not maximized when treated with 23 to 46 g ha^{-1} at the two- to three-lf

timing or 116 g ha^{-1} at the PI timing, seed production was halted. As with other evaluated rice types, lesser yield reductions for evaluated rates of 23 to 93 g ha^{-1} applied at PI appear to be attributed to late season regrowth and tillering. This further highlights that early management of Mermentau is critical to prevent seed production and prevent spread of viable seed that can germinate and repopulate infested areas.

In conclusion, the utility of quizalofop for weedy rice control provides growers with an optimal weed management program when IR hybrid and inbred weedy rice is present. These data indicate that not all rice types can be managed the same, due to differential tolerance as observed in this study (Tables 4.2, 4.3, and 4.4). By delaying the initial application to PI, the two rice inbred lines and the hybrid evaluated resulted in reduced control, larger plant heights, increased biomass, and increased yield. If adequate control is not achieved with a single application, it is also important to consider the use of a sequential application of quizalofop. Furthermore, this sequential application should be timely so that optimum weedy rice control is maintained during the critical period of 1- to 6-weeks after cultivated rice emergence where competition and interference has the greatest effect on cultivated rice yields (Zhang et al. 2003). While previous research has shown that relying on reduced rates of a herbicide can cause rapid evolution and selection for herbicide resistance, this research is intended to show that initial control can be achieved with less product for all three evaluated rice types (Manalil et al. 2011). This in turn allows for more product to be conserved and then applied when new weedy rice emerges or for control of other problematic grass weeds within the field. It is also important to note that these data represent a single application of quizalofop made to mimicked volunteer rice. Therefore, control levels need to be evaluated when a sequential application is made following lower than

the labeled rate to determine what rate of quizalofop is needed to achieve adequate control and/or seed head suppression.

Chapter 5. Summary

Florpyrauxifen-benzyl (Loyant™, Corteva Agrisciences, Indianapolis IN) is a postemergence herbicide that was released for commercial use in the 2018 growing season. This herbicide is useful for the control of problematic broadleaf, grass, and sedge weeds in rice (Perry et al. 2015; Telo et al. 2018a, 2018b). Florpyrauxifen is also a synthetic auxin and a member of the arylpicolinate chemical family. The chemical structure of florpyrauxifen is composed of a highly substituted 4-amino-pyridine ring (4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxyphenyl)-5-fluoro-pyridine-2-benzyl ester) that requires a hydrolysis reaction to be converted to its active acid form to achieve activity in target plants (Anonymous 2017a). Furthermore, research has shown that optimal absorption and translocation of florpyrauxifen is achieved with soil moisture at or above field capacity (Miller and Norsworthy 2018a). As a result, the majority of florpyrauxifen applications are made aerially on flooded rice fields and capable of moving off-target. Symptomology of florpyrauxifen exposure to susceptible plants can vary depending on the rate of the applied herbicide. Low-rate exposure typically results in chlorosis of leaves and terminal buds, leaf cupping, and epinasty of stems and petioles. High-rate exposure will typically result in stem cracking, terminal death, and necrosis of leaves and other plant tissue (Soloman and Bradley 2014).

When a herbicide is applied to a crop there is always a risk for off-target deposition of the applied herbicide. Herbicides can move off-target via three methods: vapor drift, particle drift, and tank contamination (Wolf 2000). Vapor drift or volatility is the result of a herbicide being converted from a solid or liquid chemical state to a gaseous state and occurs after spray droplets have reached their destination (Taylor and Spencer 1990). The volatility of a herbicide is largely dependent on its chemical formulation and is exacerbated by low relative humidity, high

temperatures, and high wind speeds (Egan and Mortenson 2012; Grover et al. 1972; Harper et al. 1983). The herbicide in the gaseous form can then travel great distances and deposit on susceptible vegetation. Synthetic auxin herbicides are notorious for volatilization after application when conditions are favorable, with recurring examples of 2,4-dichlorophenoxy acetic acid (2,4-D) and dicamba vapor drift after being applied to soybean or cotton noted (US EPA 2017a).

Particle drift is the movement of physical spray droplets that occurs at the time of application. Particle drift is influenced by atmospheric stability, wind speed, spray boom height, applicator speed and nozzle selection (Hobson et al. 1993). Spray droplets are categorized based on their diameter and range from very fine to very coarse. The size of spray droplets is the major determinant of the drift potential of herbicide sprays and its effect has been studied extensively (Mueller and Womac 1997; Whisenant et al. 1993; Yates et al. 1976). Spray droplet size can be modified by changes in operating pressure or by changing the nozzle orifice size. Spray droplets smaller than 150 micrometers (μm) are most susceptible to particle drift (Etheridge et al. 1999). All herbicides are susceptible to physical drift; however, herbicides with auxin activity have a history of vapor drift. This is especially true with 2,4-D and dicamba (Hatterman-Valenti et al. 1995; Hee and Sutherland 1974). Drift from herbicides with auxin activity like 2,4-D and dicamba is a current issue of major importance within the agricultural community that can result in serious crop damage (Riar et al. 2013b).

With soybean [*Glycine max* (L.) Merr.] and rice (*Oryza sativa* L.) crops being cultivated in adjacent fields in many areas throughout Louisiana, there is an increased chance of off-target movement of applied herbicides like florpyrauxifen from rice to soybean. Furthermore, the active planting window of rice and soybean has considerable overlap in the state of Louisiana. This

creates many scenarios where vulnerable soybean plants at a young growth stage are at risk to exposure from herbicides being applied to neighboring rice. In many cases, herbicides that are used in one of these crops are not compatible with the other and therefore can be injurious to unintended targets. Therefore, studies were conducted to determine the effect of florpyrauxifen exposure to soybean at the V4 to V5 and R1 to R2 growth stages and its potential for volatilization after application.

Research was conducted in 2018, 2019, and 2021 in field studies at the Rice Research Station (RRS) near Crowley, Louisiana, and the Dean Lee Research and Extension Center (DLREC) near Alexandria, Louisiana to evaluate the effect that florpyrauxifen has on soybean growth and yield. Results indicate that soybean response to florpyrauxifen treatment is largely dependent on the rate of florpyrauxifen and the growth stage of soybean at the time of application. Previous research has concluded that concentrations of herbicides that move off-target and deposit on susceptible vegetation can vary from 0.01 to 10% of the applied rate (Al-Khatib and Peterson 1999). Based on these results, soybean in this trial at the V4- to V5-growth stage are susceptible to off-target deposition of florpyrauxifen at a rate equaling 6.25% or 1.84 g ha^{-1} of the full rate of 30 g ha^{-1} of florpyrauxifen which resulted in a 59% yield reduction to treated plants compared with nontreated plants. Furthermore, soybean at the R1 to R2 growth stage are also susceptible to off-target deposition of florpyrauxifen as treatment with rates equaling 6.25% or 1.84 g ha^{-1} and 1.5% or 0.46 g ha^{-1} of the full rate with 87 and 36% yield reductions, respectfully, for the treated plants compared with nontreated plants.

Research was conducted in 2019 and 2020 in field studies at the RRS near Crowley, Louisiana, and the DLREC near Alexandria, Louisiana to evaluate the potential of florpyrauxifen volatilization following an application made to rice foliage, soil, or water. Results indicate, the

potential for florpyrauxifen volatilization after application is low. This low potential can be partially explained by the low vapor pressure of 0.032 megapascals (mPa) of florpyrauxifen compared with 1.67 mPa for dicamba (Lewis et al. 2016). To confirm these results, it would be useful to sample for airborne florpyrauxifen particulate using a polyurethane foam (PUF) air sampler to confirm volatilization. Furthermore, these results suggest that reported cases of off-target movement of florpyrauxifen can more than likely be attributed to particle drift rather than vapor drift. Research conducted by Walker et al. (2019) to evaluate soybean tolerance to simulated florpyrauxifen particle drift supports this conclusion with an application of 0.03 g ai ha^{-1} of florpyrauxifen to R1 soybean resulting in a 15% yield reduction. While the potential for florpyrauxifen volatilization is low, it is still important for growers and applicators to be mindful of weather conditions when applying any herbicide. As previously stated, vapor drift is just one of many methods that herbicides can move off-target. Particle drift is still the largest occurrence of off-target movement and has the potential to occur when applying any herbicide if weather conditions are favorable for off-target movement. These data provide insight to growers and applicators on what to expect if injury is observed near a field where an application of florpyrauxifen occurred. Based on these data, it can be assumed that if injury is observed, it is most likely due to particle drift that occurred at the time of application.

Arlyoxyphenoxypropionate herbicides inhibit the enzyme acetyl-Coenzyme-A carboxylase (ACCase). This enzyme is responsible for catalyzing the first committed step of fatty acid synthesis: the carboxylation of acetyl-CoA to malonyl-CoA (Burton et al. 1989, Focke and Lichtenthaler 1987). By inhibiting fatty acid synthesis, production of essential phospholipids crucial for membrane structure in new cells is halted. Herbicides in this group are particularly effective on grass species as broadleaf species possess inherent tolerance due to an insensitive

ACCase enzyme (Stoltenberg et al. 1989). The Provisia™ production system (BASF Corporation, Raleigh NC) is a new herbicide-resistant rice technology that was first released in 2018. This system enables postemergence applications of quizalofop (Provisia™), an ACCase-inhibiting herbicide to be made directly over the top of the resistant rice (Guice et al. 2015). Quizalofop is commonly used for the control of problematic annual and perennial grass weeds (Parsells 1985).

The most troublesome weed that rice producers encounter is red rice. Red rice, often referred to as “weedy rice,” is a relative of cultivated rice and has several physiological characteristics that allow it to outcompete cultivated rice such as: a faster growth rate, greater maximum height, increased tillering capacity, and larger leaf area (Dodson 1898; Dodson 1900; Smith et al. 1977; Smith 1988; Vincenheller 1906). Weedy rice is a conspecific weed of cultivated rice and refers to a complex of volunteer hybrids, outcrosses, and true red rice.

Quizalofop is labeled for the control of volunteer rice from the one- to four-leaf growth stage with a suggested minimum single application rate of 100 g ai ha^{-1}. Furthermore, the total use rate per season is 239 g ha^{-1}, which means growers are only allowed two applications per season (Anonymous 2017b). It has been suggested that the current two application limit should be extended to three applications using lower rates, and that adequate control of red rice and other grass weeds can be achieved past the four-leaf growth stage. If these lower rates provide adequate control of these weeds, the result could be the allocation of another quizalofop application if needed and consequently conserving more product for use later in the growing season should a weed problem arise. Furthermore, if adequate control can be achieved past the four-leaf growth stage, the utility of this herbicide for the control of weedy rice will be greatly enhanced and its window for use lengthened. Therefore, research was conducted to evaluate the

activity of quizalofop on two rice lines and a hybrid at the two- to three-lf or panicle initiation (PI) growth stages to mimic activity on different types of outcrossed weedy rice.

Results indicated that not all rice types can be managed the same, due to differential tolerance as observed in this study (Tables 4.2, 4.3, and 4.4). By delaying the initial application to PI, the two rice inbred lines and the hybrid evaluated resulted in reduced control, increased plant heights, increased biomass, and increased yield. If adequate control is not achieved with a single application, it is also important to consider the use of a sequential application of quizalofop. Furthermore, this sequential application should be timely so that optimum weedy rice control is maintained during the critical period of 1- to 6-weeks after cultivated rice emergence where competition and interference has the greatest effect on cultivated rice yields (Zhang et al. 2003). While previous research has shown that relying on reduced rates of a herbicide can cause rapid evolution and selection for herbicide resistance, this research is intended to show that initial control can be achieved with less product for all three evaluated rice types (Manalil et al. 2011). This in turn allows for more product to be conserved and then applied when new weedy rice emerges or for control of other problematic grass weeds within the field. It is also important to note that these data represent a single application of quizalofop made to mimicked volunteer rice. Therefore, control levels need to be evaluated when a sequential application is made following lower than the labeled rate to determine what rate of quizalofop is needed to achieve adequate control and/or seed head suppression.

With the release of florpyrauxifen-benzyl (Loyant®, Dow AgroSciences LLC, Wilmington DE) and a quizalofop-resistant (QR) rice cropping system (Provisia® Rice System, BASF Corporation, Research Triangle Park, NC) in 2018, it is important to understand the niche these products will fill in Louisiana rice (*Oryza sativa* L.) production. While these products will

provide exemplary control of problematic broadleaf and grass weeds, respectively, it is important to closer evaluate these products for unintended side effects resulting from their use and potential improvements in rate and timing placement (Bergeron et al. 2015a, 2015b; Perry et al. 2015; Telo et al. 2018a, 2018b; Webster 2011).

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Vita

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