2009

Integrated management of creeping rivergrass in rice

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INTEGRATED MANAGEMENT OF CREEPING RIVERGRASS IN RICE

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 School of Plant, Environmental, and Soil Sciences

By
Sunny L. Bottoms
B.S., University of Arkansas, 1997
M.S., University of Arkansas, 2005
August 2009

Acknowledgements

Without my family my achievements would not have been possible. I would like to thank my parents, Leo and Mildred Bottoms, for encouraging me to continue my education and for fostering my love of agriculture. By example they showed me that anything is possible with hard work. In addition to my parents, Nina and Jack Snyder and Tom and Sharon Hensley have been a supportive and an encouraging force in the completion of my education.

I am indebted to my husband Justin not just for his understanding, patience, devotion, motivation, and laughter, but his shared love of farming, hunting, and fishing as well. I am grateful Justin was willing to quit a career and pursue a PhD also. I also want to thank my daughter, Georgia, who is my inspiration to persevere. I want her to know anything is possible and to never give up on a dream.

Thanks to my three brothers, especially Wayne Bottoms, who was there for me through all of the peaks and valleys. And finally my family would not be complete without Mrs. Betty Fetter whom has filled my life with love, laughter, and friendship.

I owe my sincere appreciation to Dr. Eric Webster for his guidance and support not only in my education but also in life. Not only has he been a wonderful mentor but a great friend.

I would like to thank the Louisiana State University AgCenter, the School of Plant, Environmental, and Soil Sciences, and the Louisiana Rice Research Board for the opportunity, support, guidance, and financial funding that I have received. I would also like to include Mr. Brian Leonards for allowing the use of his land and resources.

I am grateful to the members of my committee, Dr. James Griffin, Dr. Steve Linscombe, Dr. Donnie Miller, and Dr. Jeff Davis, who have shared their ideas, time, instruction, and in some cases sweat, in the development and fulfillment of this research.

Over the course of my education, I have had the pleasure of working with many people that have influenced me and made all of this possible. To these unnamed individuals I am very grateful. It is only befitting that I personally acknowledge those who have contributed their time and sweat in the collection of my data that composes this dissertation. So to Dr. Wei Zhang, Justin Hensley, Tyler Carlson, Emily Thevis, and Melanie Pasqua, I appreciate you all for your hard work.

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Abstract

Studies were conducted to evaluate growth and reproductive capabilities of creeping rivergrass in response to flood depth, burial depth, desiccation, herbicide programs and interference with rice.

Seed production of a natural population of creeping rivergrass was 0.8 seeds per panicle. Germination was 45% and seedling vigor was poor. Flowers from surviving seedlings were male sterile.

A 5 and 10 cm flood depth increased fresh weight, stolon length, and node production of creeping rivergrass compared with non-flooded plants. However, depths at 15 and 20 cm did not differ from no-flood; therefore permanent flooding should be delayed until rice can survive a deep flood.

Burial of stolons 10 to 20 cm deep prevented emergence and reduced viability. Deep burial of rhizomes prevented emergence but did not reduce viability. Stolon fragmentation due to deep tillage and burial greater than 5 cm, or placement of rhizomes on the soil surface decreases emergence and viability of creeping rivergrass vegetative structures. Desiccating stolons from 35 to 25% of initial fresh weight reduced germination, growth, and potential colonization rate of creeping rivergrass.

In competition studies creeping rivergrass above ground biomass was reduced when grown with rice seeded at >45 kg/ha. Rice grain yield was reduced 17 and 29% when creeping rivergrass was planted at densities of 26 and 52 plants/ha, respectively.

Emergence of creeping rivergrass was 98% at 31 C and less than 2% at 15 and 11 C suggesting that planting of rice in cooler temperatures may allow a competitive advantage for rice.

Creeping rivergrass grown from single node stolon segments, multiple node stolon segments, and rhizomes were treated with various herbicides to evaluate efficacy. A herbicide program for the management of creeping rivergrass should include glyphosate as a burndown treatment prior to

planting or during fallow periods. A Clearfield rice variety or hybrid should be selected which allows the use of two applications of imazethapyr, and cyhalofop used as needed throughout the season.

Employing a herbicide program coupled with integrated management strategies such as tillage, planting date, and increased rice seeding rates decreases the competitiveness of creeping rivergrass.

Chapter 1

Literature Review

Creeping rivergrass [*Echinochloa polystachya* (Knuth) Hitch.] is an invasive aquatic perennial grass native to South America (Michael 1981). It is currently infesting approximately 5,000 to 6,000 hectares of rice (*Oryza sativa* L.) and crawfish production in Louisiana (Saichuk 2008). Practices associated with rice and crawfish production coupled with the sub-tropical climate of south Louisiana create optimal conditions for growth and encourage the spread of creeping rivergrass.

Creeping rivergrass has become problematic in the central Amazon due to the competitiveness of the weed with the native flora through formation of monotypic stands (Csurhes and Edwards 1998; Hedges et al. 1986; Piedade et al. 1991). The ability of creeping rivergrass to thrive in the Amazon region could be due to its adaptability to rising water levels and/or its ability to sequester large amounts of nutrients in leaves, roots, and stem tissues from the nutrient rich waters (Piedade et al. 1997). In this region, creeping rivergrass exhibits a pseudo-annual life cycle in sync with the cycle of water levels in the central Amazon (Piedade et al. 1997). New growth initiates in December/January maintaining a canopy above rising floodwaters up to 15 m, growing up to 4 cm/day (Junk and Piedade 1993; Pompeo et al. 1999; Pompeo et al. 2001). Adventitious roots form during the rise in water and by April make up 75% of the live root mass (Piedade et al. 1992). During initial flooding of the Amazon floodplain, nutrient rich waters can contain 221 mg/m^3 N and 100 mg/m^3 P (Morrison et al. 2000). When floodwaters are at the deepest levels, leaf nitrogen (N) and phosphorus (P) concentrations peak up to 24 and 1.9 g/kg, respectively (Pompeo et al. 1999). Peak carbon (C) concentrations occur up to 463 and 452 mg/gDW in the stems and roots, respectively. In October/November the species enters the terrestrial phase where existing stems die back. As plant material senesces, a portion of N and P is redistributed to the growing points and the relative share of C in its live biomass increases.

In south Louisiana creeping rivergrass has become a problem in rice and crawfish production (Saichuk 2008). Although the habitat is quite different from that of the central Amazon, management practices associated with rice and crawfish production are sufficient for creeping rivergrass survival. Creeping rivergrass grows prolifically in areas with moist, fertile soils and annual rainfall greater than 800 mm (Cshurhes and Edwards 1998). The annual rainfall for south Louisiana is 1400 to 1600 mm (LOSC 2009). Rice fields in a rice-crawfish rotation are flooded 9 to 11 months per year (Saichuk 2008). The use of implements for rice seedbed preparation and for harvesting crawfish increase the spread of vegetative structures to other areas via contaminated equipment. Approximately one-quarter of irrigation water used for rice is surface water (USGS 2003). Since creeping rivergrass is distributed in many waterways in south Louisiana, the use of surface water to irrigate fields could also increase spread of this weed (Webster 2009).

In rice and crawfish production fields, creeping rivergrass produces an extensive network of stolons from which new plants arise. A single creeping rivergrass plant can form 100,000 stolon/ha measuring 33 km/ha in total length (Griffin et al. 2008). Creeping rivergrass also produces an extensive network of ginger-like rhizomes (Urbatsch 2009). Two types of rhizome structures have been observed in rice fields with dense populations, single rhizome segments and highly developed multi-rhizome clusters (Urbatsch 2009). The rhizome segments are more commonly associated with young plants. As the plants mature, more highly developed multi-rhizome clusters are formed. These structures are not mentioned in other research studies, most of which were conducted in the Amazon flood basin. It is possible that these structures are more prevalent in shallow flood situations of rice fields and may store larger concentrations of nutrients than stolons, leaves, or roots. There are no documented cases to support these theories.

Creeping rivergrass produces a panicle and is capable of producing a significant amount of seed in the central Amazon; although vegetative propagation is more frequent (Piedade et al. 1992). In this region seedlings are thought to be responsible for formation of new colonies. In Australia seed production and viability of creeping rivergrass are very low (PIER 2000). Seed production is thought to be negligible in south Louisiana as well (Bottoms et al. 2008).

Seed production of other aquatic perennial plants that reproduce primarily vegetatively, such as water hyacinth [***Eichhornia crassipes*** (Mart.) Solms] is believed to be highly influenced by environmental factors (Barrett 1980). Water hyacinth exhibited a high degree of seed fertility in controlled pollination studies but not in natural populations (Barrett 1977; Barrett 1979; Barrett 1980). It is possible that creeping rivergrass seed production is influenced by environmental factors in a similar manner. Seed viability of barnyardgrass [***Echinochloa crus-galli*** L. Beauv.], an annual species of ***Echinochloa***, is dependent on seed weight and enforced dormancy (Barrett and Wilson 1983). Dormancy in this annual species can be enforced by burial of seed or by flooded conditions (Barrett and Wilson 1983; Honek and Martinkova 1992).

Irrigation method and rice planting method could influence colonization of creeping rivergrass in fields. Approximately 50% of rice in Louisiana is water-seeded, a cultural method historically used to suppress red rice [***Oryza punctata*** Kotzchy ex Stued.] (Linscombe 2009). Water-seeding is also used when excessive rainfall prevents drill-seeding (Linscombe et al. 1999). Water-seeding involves in most cases pregerminated rice seed aerially broadcast into a shallow flood, approximately 7 to 10 cm deep. Following planting, one of three flooding systems is implemented: delayed flood, pinpoint flood, or continuous flood.

Flooding system could influence growth of creeping rivergrass by affecting the competitiveness with rice. In the delayed flood system after seeding, the field is drained for 3 to 4 weeks before the permanent flood is established (Linscombe et al. 1999). The pinpoint flood involves draining the field approximately 1 to 7 d after seeding to allow for rice seedling establishment before establishing the permanent flood. Flood depth is gradually increased allowing the leaf tips of rice to remain above the water level. In the continuous flood system a draining period is eliminated.

It has been observed that creeping rivergrass is easier to manage when fields are fallowed and tilled (Webster 2009). Tillage reduces plant stolons and rhizomes into fragments and buries the plant segments below the soil surface (Ashton and Monaco 1991). Wilcut et al. (1988) reported vegetative emergence from rhizomes of cogongrass [*Imperata cylindrica* (L.) P. Beauv.] and torpedograss [*Panicum repens* L.] was significantly reduced at burial depths greater than 4 cm. However, the decrease in emergence was much greater for cogongrass which may explain the reason it can be controlled by cultivation (Peng 1984). Hossain et al. (1999), reported a difference in emergence of rhizomes and ginger-like rhizomes of torpedograss when burial depth varied. Vegetative emergence from 1-node rhizome segments was reduced at burial depths greater than 5 cm. Emergence increased at deeper burial depths as node number increased from 1 to 8 nodes; however, emergence from rhizomes did not decrease until burial depth reached 20 to 30 cm. Quackgrass [*Agropyron repens* (L.) P. Beauv.], another perennial grass, had a similar trend with 2.5 and 7.5 cm long rhizomes. The 2.5 cm rhizomes desiccated at 10 cm burial and only 28% of 7.5 cm rhizomes desiccated at 10 cm (Turner 2006).

Griffin et al. (2008) conducted research on shoot emergence from creeping rivergrass single-node stolon segments at various depths. Shoot emergence from creeping rivergrass stolon segments was highest at depths of 1.3 cm and decreased 31, 44, and 25% at depths of 0, 2.5, and 5.0, respectively. No emergence was observed at depths of 10 and 20 cm. However, no research has been published on creeping rivergrass vegetative emergence from rhizomes.

In addition to burial of stolons and rhizomes, the fragmentation of these structures by tillage should limit the amount of carbohydrate reserves for vegetative emergence and accelerate desiccation of these structures (Wilcut et al. 1988). Air drying cogongrass, torpedograss, and johnsongrass rhizomes 35 to 60% of initial fresh weight had no effect on subsequent re-growth. Creeping rivergrass rhizomes possess more carbohydrate storage than stolons (Piedade et al. 1991). However, creeping rivergrass re-growth is impaired when fields are drained, allowed to air dry, and tilled repeatedly (Webster 2009).

Environmental and cultural practices associated with rice production create favorable conditions for growing and reproducing many terrestrial, aquatic and semi-aquatic weeds (Smith 1988). Rice yield and growth is affected by interference of more than 70 weed species causing an average yield loss of 17% (Barrett 1983; Barrett and Seaman 1980; Smith 1983; Smith et al. 1977). The most common rice weed species are barnyardgrass [***Echinochloa crus-galli*** (L.) P. Beauv.], junglerice [***Echinochloa colona*** (L.) Link], broadleaf signalgrass [***Urochloa platyphylla*** (Muno ex. C. Wright) R.D. Webster], ducksalad [***Heteranthera limosa*** (Sw.) Willd], hemp sesbania [***Sesbania herbacea*** (Mill.) McVaugh], red rice [***Oryza punctata*** Kotzchy ex Steud.], sprangletop species [***Leptochloa*** spp.] and sedges [***Cyperus*** spp.](Chandler 1981; Smith et. al. 1977). Grasses are most prevalent of these weeds.

Red rice, a very important weed in rice production, reduced rice growth and grain yield even at low plant populations (Estorninos et al. 2005; Kwon et al. 1991; Ottis et al. 2005). At red rice densities of 1 to 40 plants/m^2 rice grain yield for the older rice varieties 'Newbonnet' and 'Lemont' was reduced 178 and 272 kg/ha per red rice plant/m^2, respectively (Kwon et al. 1991). In newer rice varieties, 'CL 161', 'XL8' and 'Cocodrie', rice grain yield was reduced between 100 and 755 kg/ha depending on cultivar (Kwon et al. 1991; Ottis et al. 2005). Estorninos et al. (2005) reported red rice populations of 25 to 51 plants/m^2 reduced rice tiller density 20 to 48% and rice grain yield 60 to 70%. Leon et al. (2005), reported red rice populations of 20 plants/m^2 reduced dry weight of water-seeded 'CL 121', Cocodrie, and 'Drew' 40 to 50% and panicle weight 50 to 60% compared with the red rice-free control.

Echinochloa spp., particularly barnyardgrass and junglerice, are considered the most important weeds in rice production in the world and the most common weeds found in Louisiana rice production (Holm et al. 1977; Valverde et al. 2001; Webster 2004). Stauber et al. (1991) reported a decrease in Newbonnet and Lemont rice yield of 301 and 257 kg/ha, respectively, per barnyardgrass plant as density increased from 1 to 40 plants/m^2. *Echinochloa* spp. are genetically similar to creeping rivergrass; however, creeping rivergrass is a perennial and reproduces primarily by stolons rather than seed.

Griffin et al. (2008) evaluated growth parameters of creeping rivergrass stolon segments planted at densities of 1 to 52 plants/m^2 and a constant rice seeding rate of 78 kg/ha. Creeping rivergrass produced total above ground stolon length of 15 to 318 km/ha and above ground fresh weight of 130 to 1,270 kg/ha 100 days after study initiation. Creeping rivergrass plants also produced 290,000 to 2.8 million nodes per hectare, demonstrating the growth and reproductive potential.

Torpedograss (*Panicum repens* L.), a perennial semi-aquatic grass, reproduces both sexually and asexually (Wilcut et al. 1988). Initiation of new growth from rhizomes was 92 to 96% at air temperatures of 20 to 35 C, but new growth did not occur at ≤5 and ≥45 C. Understanding the ideal temperature range for initiation of growth in creeping rivergrass could prove important in developing creeping rivergrass integrated management programs. The southern rice growing region in Louisiana has average low and high temperatures of 4 and 17 C, respectively, in January and 23 and 34 C, respectively, in July with an average annual temperature of 21 C (LOSC 2009). Slaton et al. (2003) reported the average daily low and high air temperatures for optimum rice seeding of 8 to 20 C, which corresponds to February 16 through March 28 in Acadia Parish, Louisiana. The same study also reported that 50% of the rice in Acadia Parish, Louisiana is seeded by the second week of April. The LSU AgCenter recommends seeding rice in the coastal parishes between March 15 and April 20 or when the average daily temperature is above 13 C (Anonymous 2007). In respect to management of creeping rivergrass it is possible that early planting of rice could provide a competitive advantage.

In rice fields with continuous rice production or in fields where rice and crawfish are grown in rotation, creeping rivergrass can not be managed with herbicides alone (Bottoms et al. 2008; Griffin et al. 2008). It is important to understand the biology and competitiveness of creeping rivergrass in order to develop integrated management programs. Therefore, the objectives of this research were to evaluate the interference of creeping rivergrass with rice and the effect of temperature on creeping rivergrass vegetative germination.

A creeping rivergrass management program must include a fallow period and cultivation, along with a herbicide program that includes high rates of glyphosate (Bottoms et al. 2009). Under this management program, cyhalofop[1] at 208 g ai/ha early postemergence (EPOST) followed by (fb) 315 g/ha late postemergence (LPOST) or imazethapyr[2] at 70 g ai/ha at very early postemergence (VEPOST) fb 70 g/ha LPOST controlled creeping rivergrass 85% (Webster et al. 2007). Bispyribac[3] at 22 g ai/ha EPOST fb 22 g/ha LPOST, fenoxaprop[4] at 66 g ai/ha EPOST fb 86 g/ha LPOST, and penoxsulam[5] at 50 g ai/ha MPOST resulted in at least 65% control at 7 DAT. When data were averaged across herbicide treatments creeping rivergrass control was 81 to 84% 7 to 21 DAT, 77% at 28 DAT, and 63% at 49 DAT, indicating regrowth occurred as the season progressed.

A glasshouse study at Louisiana State University evaluated the activity of the following herbicides: bispyribac at 22 g/ha; cyhalofop at 314 g/ha; fenoxaprop/s[6] at 86 g/ha; fenoxaprop/s at 46 g/ha plus fenoxaprop at 40 g/ha; glufosinate[7] at 497 g ai/ha; glyphosate[8] at 1260 g ae/ha; imazethapyr at 70 g ai/ha; penoxsulam at 50 g/ha; propanil[9] at 3364 g ai/ha; and quinclorac[10] at 560 g ai/ha (Griffin et al. 2008). Cyhalofop, glyphosate, glufosinate, imazethapyr, fenoxaprop/s, and penoxsulam reduced fresh weight 25 to 50% at 14 DAT and 63 to 80% at 28 DAT compared with the nontreated. Propanil reduced fresh weight 25% at 14 DAT and 20% at 28 DAT compared with the nontreated, indicating regrowth; however, quinclorac increased fresh weight

[1]Clincher® SF herbicide label. Dow AgroScience, Indianapolis, IN 46268.
[2]Newpath® herbicide label. BASF Corporation, Research Triangle Park, NC 27709.
[3]Regiment™ herbicide label. Valent Corp., Walnut Creek, CA 94596
[4]Whip® 360 herbicide label. Bayer CropScience, P.O. Box 12014, 2 T.W. Alexander Dr., Research Triangle Park, NC 27709.
[5]Grasp® herbicide label. BASF Corporation, Research Triangle Park, NC 27709.
[6]Ricestar HT® herbicide label. Bayer CropScience, P.O. Box 12014, 2 T.W. Alexander Dr., Research Triangle Park, NC 27709.
[7]Ignite® herbicide label. Bayer CropScience, P.O. Box 12014, 2 T.W. Alexander Dr., Research Triangle Park, NC 27709.
[8]Roundup WeatherMax® herbicide label. Monsanto Co., St. Louis, MO 63167.
[9]Stam® M4 herbicide label. Dow AgroScience, Indianapolis, IN 46268.
[10]Facet® herbicide label. Dow AgroScience, Indianapolis, IN 46268.

by 24% compared with the nontreated. Use of propanil and quinclorac is not recommended for control of creeping rivergrass.

The objectives of this research were to 1) determine seed production and viability and to determine how flood depth, burial depth and desiccation affect creeping rivergrass growth and reproductive potential; 2) evaluate the interference of creeping rivergrass with rice and the effect of temperature on creeping rivergrass vegetative germination; 3) evaluate the effects of common rice herbicides on creeping rivergrass growth and vegetative reproductive potential.

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Chapter 2

Impact of Management Practices on Creeping Rivergrass Growth and Reproduction

Creeping rivergrass [*Echinochloa polystachya* (Knuth) Hitch.] is an invasive aquatic perennial grass native to South America (Michael 1981). It is currently infesting approximately 5,000 to 6,000 hectares of rice (*Oryza sativa* L.) and crawfish production in Louisiana (Saichuk 2008). Practices associated with rice and crawfish production coupled with the sub-tropical climate of south Louisiana create optimal conditions for growth and encourage the spread of creeping rivergrass.

Creeping rivergrass grows prolifically in areas with moist, fertile soils and annual rainfall greater than 800 mm (Cshurhes and Edwards 1998). The annual rainfall for south Louisiana is 1400 to 1600 mm (LOSC 2006). Rice fields in a rice-crawfish rotation are flooded from 9 to 11 months per year (Saichuk 2008). During this time, the use of implements for rice seedbed preparation and for harvesting crawfish may increase the spread of vegetative structures to other areas through contaminated equipment.

Creeping rivergrass has become problematic in the central Amazon due to competitiveness with native flora and by forming monotypic stands (Csurhes and Edwards 1998; Hedges et al. 1986; Piedade et al. 1991). The ability of creeping rivergrass to thrive could be due to its adaptability to rising water levels and/or its ability to sequester large amounts of nutrients in leaves, roots, and stem tissues (Piedade et al. 1997). Creeping rivergrass exhibits a pseudo-annual life cycle in sync with the cycle of water levels in the central Amazon (Piedade et al. 1997). New growth initiates in December/January maintaining a canopy above rising floodwaters up to 15 m, growing up to 4 cm/day (Junk and Piedade 1993; Pompeo et al. 1999; Pompeo et al. 2001). Adventitious roots form during the rise in water and by April make up 75% of the live root mass (Piedade et al. 1992). During initial flooding of the Amazon floodplain, nutrient rich waters can contain 221 mg/m^3

N and 100 mg/m^3 P (Morrison et al. 2000). When floodwaters are at the deepest levels, leaf nitrogen (N) and phosphorus (P) concentrations peak up to 24 and 1.9 g/kg, respectively (Pompeo et al. 1999). Peak carbon (C) concentrations occur up to 463 and 452 mg/gDW in the stems and roots, respectively. In October/November the species enters the terrestrial phase where existing stems die back. As plant material senesces, a portion of N and P is redistributed to the growing points and the relative share of C in its live biomass increases.

Creeping rivergrass produces a panicle and is capable of producing a significant amount of seed; although vegetative propagation is more frequent (Piedade et al. 1992). In this region seedlings are thought to be responsible for formation of new colonies. In areas, such as Australia, creeping rivergrass primarily reproduces vegetatively, but does produce a panicle, though seed production and viability are thought to be very low (PIER 2000). Seed production is thought to be low in south Louisiana (Bottoms et al. 2008).

Seed production of other aquatic perennial plants that reproduce primarily vegetatively, such as water hyacinth [***Eichhornia crassipes*** (Mart.) Solms] is believed to be highly influenced by environmental factors (Barrett 1980). Water hyacinth exhibited a high degree of seed fertility in controlled pollination studies but not in natural populations (Barrett 1977, 1979, 1980). It is possible that creeping rivergrass seed production is influenced by environmental factors in a similar manner. Seed viability studies of barnyardgrass [***Echinochloa crus-galli*** L. Beauv.], an annual species of ***Echinochloa***, indicate viability is dependent on seed weight and enforced dormancy (Barrett and Wilson 1983). Dormancy in this annual species can be enforced by burial of seed or by flooded conditions (Barrett and Wilson 1983; Honek and Martinkova 1992).

Irrigation method and rice planting method could influence colonization of creeping rivergrass in fields. Approximately one-quarter of the irrigation water used for rice is surface water (USGS 2003). Since creeping rivergrass is distributed in many waterways in south Louisiana, the use of surface water to irrigate fields could increase the spread of this weed (Webster 2009).

Approximately 50% of rice in Louisiana is water-seeded, a cultural practice historically used to suppress red rice [***Oryza punctata*** Kotzchy ex Stued.] (Linscombe 2009). Water-seeding is also used when excessive rainfall prevents drill-seeding (Linscombe et al. 1999). Water-seeding involves pregerminated rice seed, in some cases non-pregerminated seed, to be aerially broadcast into a shallow flood, approximately 7 to 10 cm deep. Following planting, one of three flooding systems is implemented: delayed flood, pinpoint flood, or continuous flood.

Flooding system could influence growth of creeping rivergrass by affecting the competitiveness with rice. In the delayed flood system after seeding, the field is drained for 3 to 4 weeks before the permanent flood is established (Linscombe et al. 1999). The pinpoint flood involves draining the field approximately 1 to 7 d after seeding to allow for rice seedling establishment before establishing the permanent flood. Flood depth is gradually increased allowing the leaf tips of rice to remain above the water level. The continuous flood system remains flooded without a draining period.

It has been observed that creeping rivergrass is easier to manage when fields are fallowed and tilled (Webster 2009). Tillage reduces plant stolons and rhizomes into fragments and buries the plant segments below the soil surface (Ashton and Monaco 1991). Wilcut et al. (1988) reported vegetative emergence from rhizomes of cogongrass [***Imperata cylindrica*** (L.) P. Beauv.] and torpedograss [***Panicum repens*** L.] was significantly reduced at burial depths greater than 4 cm. However, the decrease in emergence was much greater for cogongrass which may explain the reason it can be controlled by cultivation (Peng 1984). Hossain et al. (1999), reported a difference in various lengths of rhizomes and ginger-like rhizomes of torpedograss emerged at different rates when buried at various depths. Vegetative emergence from 1-node rhizome segments was reduced at depths greater than 5 cm. Emergence increased at deeper burial depths as node number increased from 1 to 8 nodes; however, emergence of the ginger-like rhizomes did not decrease until burial depth reached 20 to 30 cm. Quackgrass [*Agropyron repens* (L.) P. Beauv.], another perennial grass, had a similar trend with 2.5 and 7.5 cm long rhizomes. The 2.5 cm rhizomes desiccated at 10 cm burial and only 28% of 7.5 cm rhizomes desiccated at 10 cm (Turner 2006).

Griffin et al. (2008) conducted research on shoot emergence from creeping rivergrass single-node stolon segments at various depths. Shoot emergence from creeping rivergrass stolon segments was highest at depths of 1.3 cm and decreased 31, 44, and 25% at depths of 0, 2.5, and 5.0, respectively. No emergence was observed at depths of 10 and 20 cm. However, no research has been published on creeping rivergrass vegetative emergence from rhizomes.

In addition to burial of stolons and rhizomes, the fragmentation of these sstructures by tillage should limit the amount of carbohydrate reserves for vegetative emergence and accelerate desiccation of these structures (Wilcut et al. 1988). Air drying cogongrass, torpedograss, and johnsongrass rhizomes 35 to 60% of initial fresh weight had no effect on subsequent re-growth. Creeping rivergrass rhizomes possess more carbohydrate storage than stolons (Piedade et al. 1991). However, in fields with creeping rivergrass it has been observed that re-growth is impaired when the field is drained, allowed to air dry and tilled repeatedly (Webster 2009).

The objectives of this research were to determine: a) seed viability; b) flood depth affects on growth; c) burial depth and stolon desiccation affects on shoot emergence from stolons.

Materials and Methods

Seed Production and Germination. Creeping rivergrass seeds were harvested in 2006 and 2007 from plants near Crowley, Louisiana. Due to shattering, 15- by 25-cm mesh bags were placed over immature creeping rivergrass panicles, secured with a wire tie and left until maturity. In 2006 and 2007, 50 and 65 panicles, respectively, were obtained and stored in a cooler at 10 C for 4 months. Seeds were extracted from panicles, glumes were removed to increase water absorption (Baskin and Baskin 2001a) and seed number per panicle was recorded.

Germination of harvested seed was tested under temperature regimes of 15, 20, 25 and 30 C. For each temperature regime, three replications consisting of 20 seeds placed in a 10- by 1.5-cm Petri dish with 9 cm germination blotters[1] on bottom and top of seeds. A preliminary germination test with 10 seeds resulted in germination of seeds exposed to 1% KNO_3 solution and no germination with water alone; therefore, the KNO_3 solution was used in the germination study for initial wetting to aid breaking of dormancy (Hilton 1984). Dishes were sealed with Parafilm M[2] to prevent moisture loss and placed in a growth chamber maintained at one of the specified temperatures and 50% rH. Light was provided by overhead 17-watt fluorescent bulbs with a minimum intensity of 169 $\mu mols/m^2/s$ photosynthetic photon flux set for a light-dark regime of 12:12 h. Seeds were watered with 5 ml deionized water at 10 d after test initiation. Germination was checked 5, 10

[1]Anchor Steel Blue Germination Blotters®, SDB 3.5. Anchor Paper Company, 480 Broadway, St. Paul, MN 55101.
[2]Parafilm M®. Pechiney Plastic Packaging, Menasha, WI 54952.

and 14 d after test initiation. A seed was considered germinated when a 2 mm radicle was visible.

Germinated seeds were planted 1.5 cm deep in 15- by 15-cm pots filled with commercial potting soil[3] and placed in a glasshouse maintained at 30:25 ± 5 C and 60 ± 10% rH. The pots were placed into 25-cm by 45-cm by 4-cm trays to allow for sub-irrigation.

Data for the germination study were arranged as repeated measures and were analyzed using the Mixed Procedure of SAS (SAS 2006) with run, rep(run), and temperature*rep(run) as random factors. Type III statistics were used to test all possible effects of fixed factors (germination) and least square means were used for mean separation at a 5% probability level ($p \leq 0.05$).

Flood Depth Study. A glasshouse study was conducted to evaluate the effect of flood depth on the growth of creeping rivergrass from stolon segments. The study was conducted once in 2005 and twice in 2006. The study design was completely randomized with eight replications. The glasshouse was maintained at a day-night temperature of 30:25 ± 5C and 60 ± 10% rH. Day length was extended to 14 h with metal halide lamps at a minimum intensity of 270 µmols^2/s photosynthetic photon flux. A sterilized Commerce silt loam (fine-silty, mixed, superactive, nonacid, thermic Aeric Fluvaquents) soil with less than 0.1% organic matter, 80.3% sand, 5.8% silt, 13.9% clay, and pH 7.0 was used. The soil was amended with 8-24-24 (N-P_2O_5-K_2O) fertilizer to simulate a pre-plant application rate of 280 kg/ha used in rice production.

Plastic pots with a volume of 37.9-L measuring 39.7-cm in diameter and 43.5-cm in height were used for this experiment. A segment of 1.9 cm diameter PVC pipe was inserted into a fitting in the bottom of each pot as an overflow, so flood depths of 0, 5, 10, 15, and 20-cm above the soil surface could be maintained. Fourteen kilograms of soil was added to each pot to a

[3]Jiffy Mix Grower's Choice®. Jiffy Products of America, Inc., 5401 Baumhart Rd., Lorain, Ohio 44053.

depth of 10 cm. The pots were divided into three equal sections using 21 gauge aluminum dividers to partition between plants. Water was then added to saturation in each container.

Creeping rivergrass stolon segments were obtained from greenhouse stock that was reared in 70-cm by 140-cm by 12-cm plastic containers and allowed to grow until stolon lengths were 110- to 125-cm. Stolon segments consisting of an individual node were trimmed to 7-cm. Three stolon segments, one per section, were introduced to each pot. Each stolon segment was inserted vertically so that the node was 2 cm below the soil surface.

The segments were allowed 5 d to allow for rooting and acclimation to the environment before appropriate flood depth was established. Water was added two times per day to maintain flood depths for the duration of the study. At 28 days after flood establishment, plants were removed and the soil was washed from the roots. Whole plant fresh weight was obtained and overall stolon length, number of nodes, and number of nodes with adventitious roots were recorded for the aerial portion.

Data were analyzed using the Mixed Procedure of SAS (SAS 2006) with run used as a random factor. Runs, replication (nested within runs), and all interactions containing either of these effects were considered random effects; treatment (flood depth) was considered a fixed effect. Type III statistics were used to test all possible effects of the fixed factor and least square means were used for mean separation at a 5% probability level ($p \leq 0.05$).

Depth of Burial - Stolons. A depth of burial study was conducted to evaluate creeping rivergrass shoot emergence from stolon nodes in a glasshouse at Louisiana State University in 2006 and 2007. A completely randomized design with eight replications was used. The glasshouse was maintained at a day-night temperature of 30:25 ± 5 C and 60 ± 10% rH. Day length was extended to 14 h with metal halide lamps at a minimum intensity of 270 $\mu mols^2/s$

photosynthetic photon flux. A sterilized Commerce silt loam soil was used as mentioned in the flood depth study. The soil was thoroughly mixed with 8-24-24 fertilizer to simulate a preplant application of 280 kg/ha used in rice production.

PVC depth tubes were constructed and soil was added according to Griffin et al. (2008). Planting depths were 1.3, 2.5, 5.0, 10.0 and 20.0-cm with no burial for comparison. Creeping rivergrass planting stock was grown and harvested as described in the flood depth study. One 7-cm single node stolon segment was inserted into each tube. The tube was tapped twice on a hard surface to allow for soil-stolon contact. The tubes were placed into 70 cm by 140 cm by 12 cm plastic containers for sub-irrigation. Griffin et al. (2008) maintained the depth tubes at field capacity. However, in this study the water level in the sub-irrigation trays was maintained daily to a depth of 2 cm above the bottom of the burial tubes so that moisture could be maintained throughout the tubes at all times.

Visual observations were made daily for 28 d to evaluate emergence. Emergence was defined as a shoot emerging at the soil line. At the end of 28 d, stolons that did not emerge from the soil line were removed from the tubes, weighed, and planted in 15 cm by 30 cm growing trays at a depth of 1.5 cm. Emergence was recorded for the next 21 d.

Data were analyzed using PROC GLIMMIX in SAS (SAS 2006). Runs and replication (nested within runs) were considered random effects; treatment (burial depth) was considered a fixed effect. Type III statistics were used to test all possible effects of the fixed factor and least square means were used for mean separation at a 5% probability level ($p \leq 0.05$).

Depth of Burial - Rhizomes. A burial depth study was conducted to evaluate creeping rivergrass shoot emergence from rhizomes in a glasshouse at Louisiana State University in 2007. The study was conducted twice using a completely randomized design with six replications. The glasshouse was maintained at a day-night temperature of 30:25 ± 5 C and 60 ± 10% rH. Day length was extended to 14 h with metal halide lamps at a minimum intensity of 270 µmols^2/s photosynthetic photon flux. A sterilized Commerce silt loam soil was used as described in the flood depth study. The soil was thoroughly mixed with 8-24-24 (N-P-K) fertilizer to simulate a preplant application of 280 kg/ha used in rice production.

Depth tubes utilized in the stolon depth of burial study were used in this study. Creeping rivergrass plants were extracted from a rice field near Kaplan, Louisiana. Rhizomes were excised from the plants, cut to a length of 7 cm, washed in deionized water, and stored overnight in a refrigerator at 10 C. Due to the large size of the rhizomes, averaging 11 g and 2.5 cm diameter, soil was filled to the planting hole, the rhizome segment was planted, and the remaining soil was filled to the indicator mark and tapped on a hard surface twice to allow for soil to rhizome contact.

Visual observations were made everyday for 28 d to evaluate emergence. Emergence was defined as a shoot emerging from the soil line. At the end of 28 d, rhizomes with no shoot emergence were removed from the tubes, weighed, and planted in 15-cm by 30-cm growing trays at a depth of 1.5 cm. Because many rhizomes germinated but did not emerge above the soil line, shoots were counted and measured for all rhizome segments. Emergence was recorded for the next 21 d. Data was analyzed as previously described using PROC GLIMMIX.

Stolon Desiccation Study. A glasshouse study was conducted to determine the effect of desiccation on stolon node viability in 2008. The design was completely randomized with a three by six factorial arrangement and eight replications. The study was conducted twice. Stolon segments containing 1, 2 and 4 nodes were obtained from glasshouse stock previously described. Each segment was weighed and allowed to air dry at room temperature to 25, 35, 45, 55, and 65% of initial fresh weight. A fresh sample was also used as the 100% of fresh weight for comparison. Following desiccation, the stolons were planted 2 cm deep in commercial potting soil previously mentioned, in 15 cm by 30 cm growing trays. All trays were irrigated to just excess daily. Shoot emergence and number of shoots was recorded 21 days after planting. Data was analyzed as previously described using PROC GLIMMIX.

Results and Discussion

Seed Production and Germination. Seed production averaged 0.8 seeds per panicle ± 2.0 (data not shown). Germination was highest, 40 and 30% at 25 and 30 C, respectively (Table 2.1). Germination decreased to 10 and 1% at 20 and 15 C, respectively. Creeping rivergrass seed production is low and based on results from this study, germination of creeping rivergrass seeds in rice culture would be unlikely. Average air temperature is between 25 and 30 C from May to August in Acadia Parish, Louisiana. During this time fields in rice production would be flooded and seed germination would be unlikely. Typically seeds of aquatic plants germinate after flood water has receded (Baskin and Baskin 2001b).

Table 2.1. Effect of temperature on germination of creeping rivergrass seeds at Louisiana State University, Baton Rouge, Louisiana in 2006 and 2007[a].

Temperature	Germination
—— C ——	——— % ———
15	1 b
20	10 b
25	40 a
30	30 a

[a]Means followed by the same letter are not significantly different at p=0.05.

Seedling vigor was poor. Only two seedlings of 45 planted survived to maturity. It was observed that flowers from these plants had no anthers. Male sterility in plants frequently occurs in cultures of plants which have been subjected to inbreeding during genetic experiments (Lewis 1941). Creeping rivergrass has long been used as forage in ponded pastures and has been naturalized in tropical and southern Africa, tropical Asia, South America, Hawaii, and Australia (Low 1997; Space et al. 2000; Cook et al.

2005). A commercial variety 'Amity' was released July 1988 in Australia in which seed production is very low (Anonymous 1988; Clem et al. 1993). According to Low (1997) creeping rivergrass has become one of Australia's five worst environmental weeds since the introduction. The biotype of creeping rivergrass in south Louisiana is unknown. However, this may explain the discrepancy in the high seed production from creeping rivergrass in Brazil versus south Louisiana (Piedade et al. 1997; PIER 2000).

Flood Depth Study. Whole plant fresh weight, total stolon length, growth rate node production, and nodes with adventitious roots were greatest at flood depths of 5- and 10-cm (Table 2.2). For all parameters measured 15- and 20-cm flood depths did not differ from the no-flood treatment; therefore, all results are presented and compared with the 5 and 10 cm flood depths.

Table 2.2. Effect of flood depth on creeping rivergrass whole plant fresh weight, total stem length, growth rate, node production and production of nodes with adventitious roots at Louisiana State University, Baton Rouge, Louisiana in 2005 and 2006.[a]

Flood depth	Whole plant fresh weight		Total stolon length		Growth rate		Node production		Nodes with adventitious roots	
- cm -	— g —		— cm —		- cm/day -		- no./plant -		- no./plant -	
0	3.9	b	73	bc	2.6	bc	8	c	2	c
5	8.7	a	172	a	6.1	a	17	a	5	ab
10	7.9	a	123	ab	4.4	ab	17	a	6	a
15	2.0	b	43	c	1.5	c	8	c	3	bc
20	0.6	b	16	c	0.6	c	3	c	2	c

[a]Means followed by the same letter are not significantly different at p=0.05.

With 0, 15, and 20 cm flood depths fresh weight was reduced to 0.6 to 3.9 g compared with 8.7 to 7.9 g in 5 and 10 cm flood depths, respectively, and stolon length was reduced 16 to 73 cm compared with 172 and 123 cm in 5 and 10 cm flood depths, respectively (Table 2.2). Growth rate was reduced from 6.1 to 4.4 cm/d with 5 and 10 cm flood, respectively, to 2.6 to 0.6 cm/d with 0, 15, and 20 cm flood. Data suggest that a deep flood (≥15 cm) could be used to decrease the growth and competitiveness of creeping rivergrass with rice. There was no difference between no flood and 15 and 20 cm flood which suggests that delayed flood establishment could also allow rice a competitive advantage over creeping rivergrass.

No more than 8 nodes were produced when flood depth was 0, 15 and 20 cm flood, compared with 17 nodes/plant in 5 and 10 cm flood, which could translate to approximately 52 to 83% reduction in population growth. Colonization was also slowed with the reduction of adventitious roots from 5 and 6 per plant with 5 and 10 cm flood, respectively, to 2 to 3 per plant with 0, 15 and 20 cm flood. Delaying flood establishment or fallowing the field (no flood) reduces biomass production and colonization. Establishment of a deep flood greater than 15 cm over newly emerging creeping rivergrass plants may also reduce population growth and colonization.

Although the use of no flood and a deep flood for management of creeping rivergrass seem contradictory as a management strategy, these two cultural practices could be readily applied to rice production. The flood depths of most rice fields in Louisiana average 7 to 15 cm after the rice stand is established (Saichuk 2008). Creeping rivergrass usually begins re-growth from stolons at the time of rice planting. Dry-seeding rice, weather permitting, would be the best option for reducing creeping rivergrass growth and vegetative reproductive ability. No flood early followed by establishment of a 15 cm flood would hinder the ability of creeping rivergrass to establish. Approximately 50% of the rice in south Louisiana is water-seeded in the pinpoint flood system. In this system, where a shallow flood is established early, creeping rivergrass would initiate growth under ideal conditions. Therefore, regardless of whether rice is dry- or water-seeded, permanent flood establishment should be delayed until rice is big enough for deep flooding.

Depth of Burial Study – Stolons. Emergence of shoots from stolons was 63 and 56% when stolon segments were buried 1.2 and 2.5 cm, respectively (Table

2.3). Emergence of shoots from stolons was reduced to 31 and 25% with no burial and burial at 5 cm, respectively, and 0% when buried 10 and 20 cm. Although emergence was reduced when shoots were not buried, fresh weight with this treatment increased 657%. Large increases in fresh weight may be consistent with maintained viability of nodes, the ability of nodes to produce shoots when under ideal conditions, which was 92% with no burial, the highest maintained viability rate of any treatment. Viability was reduced approximately 70% at 1.2, 2.5 and 5 cm depths and 100% at 10 and 20 cm depths.

Table 2.3 Creeping rivergrass shoot emergence and viability of stolon segments as affected by burial depth, Louisiana State University, Baton Rouge, Louisiana in 2006 and 2007.[a]

Burial depth	Emergence	Weight change[b]	Maintained viability
— cm —	——— % ———	——— % ———	——— % ———
0.0	31 b	657 a	92 a
1.2	63 a	112 b	33 b
2.5	56 a	166 b	33 b
5.0	25 b	88 b	25 b
10.0	0 c	29 b	0 c
20.0	0 c	28 b	0 c

[a]Means followed by the same letter are not significantly different at p=0.05.
[b]Change in weight is calculated from initial fresh weight and fresh weight at 28 DAP.

Based on these results, shallow burial, between 1 and 2.5 cm enhances the ability of shoots to emerge from stolons. Deep burial of stolons, 10 to 20 cm, prevents any emergence of shoots from stolons even after shoot is replanted to ideal planting depth. Results suggest that fields infested with creeping rivergrass may benefit from repeated deep tillage, to reduce stolon size and to increase burial depth. Shallow tillage may encourage colonization, by increasing shoot emergence from stolons and maintaining viability of vegetative structures. Even though shoot emergence from stolons was poor when stolon segments were not buried, this does not suggest no-till would be beneficial. Stolons segments used in this study were cut to 7 cm in length to mimic fragmenting of multiple tillage operations. Shoot emergence and viability of longer, multi-node stolons may be much higher based on previous research on other perennial grasses (Hossain et al. 1999).

Depth of Burial Study – Rhizomes. Vegetative germination and emergence of rhizome segments were 100% at 1.2 and 2.5 cm (Table 2.4). Vegetative germination decreased to 75 to 42% with no burial and burial at 5 to 20 cm. Emergence of shoots from rhizomes at 10 and 20 cm decreased to 33 and 0%, respectively, indicating that although germination occurred, shoots could not emerge above the soil surface within 28 d of burial. Burial did not affect viability of rhizome fragments which contradicts the affect of burial on stolon segments in the previous study. Rhizome fragments increased fresh weight 194% at 1.2 cm and 41 to 65% at 2.5 to 10 cm over the 28 d burial period. In the same time period, fresh weight decreased to -6 and -28% with no burial and burial at 20 cm. Shoot production decreased to 1.9 to 2.6 shoots/rhizome with lengths of 19 to 38 cm at 5, 10, and 20 cm and no burial compared with 5.2 and 4.1 shoots/rhizome with lengths of 74 to 90 cm at 1.2 and 2.5 cm. The decrease in biomass production indicates a decrease in creeping rivergrass competitiveness with rice.

Table 2.4. Creeping rivergrass rhizome vegetative germination, emergence, viability, shoot production, shoot length, and weight change as affected by burial depth at Louisiana State University, Baton Rouge, Louisiana in 2007.[a]

Burial depth	Germination	Emergence	Weight change	Viability	Shoots	Shoot length
– cm –	—— % ——	—— % ——	—— % ——	—— % ——	— no. —	— cm —
0.0	42 b	42 c	-28 c	50 a	1.9 b	23 b
1.2	100 a	100 a	194 a	100 a	5.2 a	90 a
2.5	100 a	100 a	62 b	100 a	4.1 a	74 a
5.0	67 b	67 b	65 b	72 a	2.4 b	38 b
10.0	75 b	33 c	41 bc	83 a	2.2 b	19 b
20.0	42 b	0 d	-6 bc	75 a	2.6 b	22 b

[a]Means followed by the same letter are not significantly different at p=0.05.
[b]Change in weight calculated from fresh weight at 28 DAP minus initial weight.

Shoot growth from rhizomes can occur even when buried, 10 to 20 cm. Viability of rhizomes can also be maintained. The decrease in fresh weight with rhizomes were on the soil surface and at 20 cm burial depth is consistent with reduction in viability compared with 1.2 and 2.5 cm burial depths. Decreases in biomass production of germinating rhizomes when not buried and buried greater than 5 cm indicates deep tillage may reduce growth, decreasing the competitiveness of creeping rivergrass with rice. The results of the two burial depth studies suggest that deep tillage resulting in stolon fragmentation and burial greater than 5 cm, and placement of rhizomes on the soil surface may be an important cultural practice in managing creeping rivergrass by reducing colonization and population.

Stolon Desiccation Study. Desiccation of stolons 45 to 65% of initial fresh weight did not reduce shoot emergence from stolons which was 63 to 81% compared with no desiccation (Table 2.5). Shoot emergence from stolons decreased to 31 and 0% for stolons 35 and 25% of initial fresh weight, respectively compared with no desiccation. Reducing shoot emergence from stolons reduces growth and colonization of creeping rivergrass. Desiccating stolons to less than 55% of initial fresh weight reduces shoot production to 0 to 0.9 shoots/stolon compared to 2 shoots/stolon, with no desiccation. Reducing shoot production alone reduces the total amount of biomass produced which could interfere with rice growth. Encouraging stolon desiccation reduces growth and colonization of creeping rivergrass plants germinating from stolon nodes. Multiple tillage operations would fragment stolons, accelerating desiccation.

It has been observed that creeping rivergrass infestations occur more frequently in fields employing a rice-crawfish rotation or staying under aquatic conditions from 9 to 11 months per year (Saichuk 2008). The spread of creeping rivergrass infestations has been relatively slow. Prior to 1993, creeping rivergrass had only been observed in Plaquemines Parish (Thomas and

Table 2.5. Effect of stolon desiccation on stolon node germination of creeping rivergrass at Louisiana State University, Baton Rouge, Louisiana in 2008.a

Percent of initial fresh weight	Time to dessiccation	Germination	Shoots produced
—— % ——	—— h ——	—— % ——	—— no. ——
25	30	0 c	0.0 d
35	24	31 b	0.6 cd
45	12	63 a	0.8 bc
55	7	81 a	0.9 bc
65	6	75 a	1.4 ab
100	0	81 a	2.0 a

[a]Means followed by the same letter are not significantly different at $p=0.05$.

Allen 1993). In 2003 it was observed in Acadia, Jefferson Davis, and Vermillion Parishes in Louisiana (Webster 2009). However, mild winters and lack of herbicide efficacy increases the rate of creeping rivergrass colonization of fields once the weed is introduced. Flood systems and duration also impact creeping rivergrass growth and colonization potential. Management recommendations for creeping rivergrass based on the results of these studies are as follows: 1) Fields should be fallowed for at least a year to allow for multiple tillage operations, 2) Rice should be drill-seeded, weather permitting, 3) The delayed flood system should be used, and 4) A delayed permanent flood management practice should be employed with a flood depth of 15 cm established as soon as possible. These cultural practices should reduce growth and node production of creeping rivergrass decreasing the rate of colonization, and the competitiveness of creeping rivergrass with rice in affected fields. These practices although effective, may not result in maximum rice yields. If not employed, rice yields will be reduced in areas where creeping rivergrass has become established.

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Chapter 3

Creeping Rivergrass *Echinochloa polystachya* Interference with Rice

Introduction

Creeping rivergrass (*Echinochloa polystachya*) is native to South America and is particularly problematic in the Amazon region where it forms monotypic stands by outcompeting the native flora (Csurhes and Edwards 1998; Hedges et al. 1986; Michael 1981; Piedade et al. 1991). In recent years creeping rivergrass has become increasingly problematic in south Louisiana rice and crawfish production systems. Although movement and spread of the species is slow, once established in an acceptable environment it is difficult to manage (Saichuk 2008). Aggressive growth habits and the competitive nature of creeping rivergrass coupled with the sub-tropical climate of south Louisiana increases the invasive potential of the weed (Junk and Piedade 1993; Piedade et al. 1991; LOSC 2008). The coastal region of Louisiana receives up to 1600 mm annual rainfall, twice the required rainfall needed for creeping rivergrass to establish and survive (Csurhes and Edwards 1998; Piedade et al. 1991). Creeping rivergrass can produce 2.3 g of dry matter per MJ of solar radiation, considered maximum for C_4 plant species, and biomass production occurs at a rate of 8 t/ha/month (Piedade et al. 1991).

Both CO_2 and water use efficiency of creeping rivergrass is comparable with those of fertilized corn in warm temperate conditions (Morrison et al. 2000). During initial flooding of the Amazon floodplain, nutrient rich waters can contain 221 mg/m^3 N and 100 mg/m^3 P. Creeping rivergrass sequesters high amounts of nutrients, with peak N and P concentrations of 24 and 1.9 g/kg (Piedade et al. 1992, 1997; Pompeo et al. 1999). In Louisiana rice requires up to 180-56-56 kg/ha N-P-K, respectively, and is grown in flooded conditions for much of the crop cycle (Anonymous 2000). Although rice is an efficient consumer of nutrients, dense stands of creeping rivergrass should be highly competitive with rice for nitrogen and phosphorus.

Environmental and cultural practices associated with rice production create favorable conditions for growing and reproducing many terrestrial, aquatic and semiaquatic weeds (Smith 1988). Rice yield and growth is affected by interference of more than 70 weed species causing an average yield loss of 17% (Barrett 1983; Barrett and Seaman 1980; Smith 1983; Smith et al. 1977). The most common rice weed species are barnyardgrass [***Echinochloa crus-galli*** (L.) P. Beauv.], junglerice [***Echinochloa colona*** (L.) Link], broadleaf signalgrass [***Urochloa platyphylla*** (Muno ex. C. Wright) R.D. Webster], ducksalad [***Heteranthera limosa*** (Sw.) Willd], hemp sesbania [***Sesbania herbacea*** (Mill.) McVaugh], red rice [***Oryza punctata*** Kotzchy ex Steud.], sprangletop species [***Leptochloa*** spp.] and sedges [***Cyperus*** spp.](Chandler 1981; Smith et. al. 1977). Of these weeds grasses are most prevalent.

Red rice, a very important weed in rice production, reduced rice growth and grain yield even at low plant populations (Estorninos et al. 2005; Kwon et al. 1991; Ottis et al. 2005). At red rice densities of 1 to 40 plants/m^2 rice grain yield for the older rice varieties 'Newbonnet' and 'Lemont' was reduced 178 and 272 kg/ha per red rice plant/m^2, respectively. In newer rice varieties, 'CL 161', 'XL8' and 'Cocodrie', rice grain yield was reduced between 100 and 755 kg/ha depending on cultivar (Kwon et al. 1991; Ottis et al. 2005). Estorninos et al. (2005) reported red rice populations of 25 to 51 plants/m^2 reduced rice tiller density 20 to 48% and rice grain yield 60 to 70%. Leon et al. (2005), reported red rice populations of 20 plants/m^2 reduced dry weight of water-seeded 'CL 121', Cocodrie, and 'Drew' 40 to 50% and panicle weight 50 to 60% compared with the red rice-free control.

Echinochloa spp., particularly barnyardgrass and junglerice, are considered the most important weeds in rice production in the world and most common weeds found in Louisiana rice production (Holm et al. 1977; Valverde et al. 2001; Webster 2004). Stauber et al. (1991) reported a decrease in Newbonnet and Lemont rice yield of 301 and 257 kg/ha, respectively, per barnyardgrass plant as density increased from 1 to 40 plants/m^2. ***Echinochloa*** spp. are genetically similar to creeping rivergrass; however, creeping rivergrass is a perennial and reproduces primarily by stolons rather than seed.

Griffin et al. (2008) evaluated growth parameters of creeping rivergrass stolon segments planted at densities of 1 to 52 plants/m^2 and a constant rice seeding rate of 78 kg/ha. Creeping rivergrass produced total above ground stolon length of 15 to 318 km/ha and above ground fresh weight of 130 to 1,270 kg/ha 100 days after study initiation. Creeping rivergrass plants also produced 290,000 to 2.8 million nodes per hectare, demonstrating the growth and reproductive potential.

Torpedograss (***Panicum repens*** L.), a perennial semi-aquatic grass, reproduces both sexually and asexually. Initiation of new growth from rhizomes was 92 to 96% at air temperatures of 20 to 35 C, but new growth did not occur at ≤5 and ≥45 C. Understanding the ideal temperature range for initiation of growth in creeping rivergrass could prove important in developing creeping rivergrass integrated management programs. The southern rice growing region in Louisiana has average low and high temperatures of 4 and 17 C, respectively, in January and 23 and 34 C, respectively, in July with an average annual temperature of 21 C (LOSC 2008). Slaton et al. (2003) reported the average daily low and high air temperatures for optimum rice seeding of 8 to 20 C, which corresponds to February 16 through March 28 in Acadia Parish, Louisiana. The same study also reported that 50% of the rice in Acadia Parish, Louisiana is seeded by the second week of April. The LSU AgCenter recommends seeding rice in the coastal parishes between March 15 and April 20 or when the average daily temperature is above 13 C (Anonymous

2007). In respect to management of creeping rivergrass it is possible that early planting of rice could provide a competitive advantage.

In rice fields with continuous rice production or in fields where rice and crawfish are grown in rotation, creeping rivergrass can not be managed with herbicides alone (Bottoms et al. 2008; Griffin et al. 2008). It is important to understand the biology and competitiveness of creeping rivergrass in order to develop integrated management programs. Therefore, the objectives of this research were to evaluate the interference of creeping rivergrass with rice and the effect of temperature on creeping rivergrass vegetative germination.

Materials and Methods

Research was conducted at the Rice Research Station near Crowley, Louisiana in 2005, 2006, and 2007. Two field studies evaluated the competitiveness of creeping rivergrass in rice and a growth chamber study evaluated creeping rivergrass growth response to temperature.

Rice Seeding Rate Study. For this study soil type was a Crowley silt loam (fine montmorillonitic, thermic, Typic Albaqualf) with pH 6.4 and 0.79% organic matter. Seedbed preparation consisted of fall and spring disking and two passes in opposite directions with a two-way bed conditioner equipped with rolling baskets and S-tine harrows set at a 6 cm depth.

Prior to study initiation, creeping rivergrass stolons were grown to a length of at least 110 cm in 70 by 140 by 12-cm plastic containers in a glasshouse as described by Griffin et al. (2008). Stolon segments obtained from greenhouse stock were cut into 8 cm segments containing one node in the center of the stolon. The stolon segments were planted vertically in cells (27-cm^3) in 28 by 48 cm growing flats on the same day rice was seeded in the field. Individual nodes were covered with 2 cm of soil and allowed to germinate and grow for 14 d prior to transplanting into the field.

Rice cultivar 'CL 131' in 2006 and 'CL 161' in 2007 was drill-seeded in 15-cm rows with a grain drill at a planting rate of 1, 23, 45, 67, 90, and 112 kg/ha. These seeding rates were based on the recommended drill-seeded rice planting density of 67 to 100 kg/ha (Anonymous 2007). Immediately after rice planting, the area was surface irrigated to a level of 1.5 cm, then drained. Fourteen days after rice seeding, creeping rivergrass planting stock, as previously mentioned, was introduced at a density of 1 plant/m^2 to a 1.5 by 5.2 m area in the middle of the 2.5 by 6.2 m plots to minimize a border effect. In order to ensure proper plant density a planting template was developed using polypropylene ropes to aid in equal spacing for introduced plants. The experimental design was a randomized complete block design with four replications.

A 10 cm permanent flood was established when rice reached five-leaf to one-tiller stage and was maintained until 2 wk prior to harvest. Fertilization consisted of 280 kg/ha 8-24-24 ($N-P_2O_5-K_2O$) preplant and 280 kg/ha 46-0-0 urea nitrogen prior to permanent flood establishment. Quinclorac at 420 g ai/ha plus 53 g/ha halosulfuron were applied at the two- to three- leaf rice stage to control weeds other than creeping rivergrass. Previous research has shown quinclorac has no activity on creeping rivergrass (Griffin et al. 2008). Treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L/ha at 193 kPa.

Four creeping rivergrass plants were removed from each plot one day before flood water was drained in preparation for harvest. Removing the plants in the flooded condition allowed the center portion and all of the rooted stolons to be easily removed from the plots with minimal damage to the aerial portions of the plants. Growth parameters measured for the four plants included fresh weight, total stolon length, number of stolons produced and number of nodes produced.

Data were analyzed using the Mixed Procedure of SAS (SAS Institute 2003) with year used as a random factor. Years, replication (nested within years), and all interactions containing either of these effects were considered random effects; rice planting rate treatments were considered fixed effects. Considering year or combination of year as random effects permits inferences about treatments over a range of environments (Carmer et al. 1989) Type III statistics were used to test all possible effects of fixed factors (growth parameters) and least square means were used for mean separation at a 5% probability level ($p \leq 0.05$).

Creeping Rivergrass Density Study. This study was prepared and conducted as described for the rice planting rate study. However, in this study rice was seeded at 100 kg/ha and creeping rivergrass plants were transplanted into plots at 0, 1, 3, 7, 13, 26, and 52 plants/m^2 as described previously.

Immediately prior to harvest rice height, number of stems, and number of panicles produced were recorded. Rice height was obtained by measuring four rice plants per treatment from the ground to the tip of the extended panicle. Stem and panicle number were obtained from whole plant samples hand harvested from 46 cm of the inner most row of each plot. Grain yield was obtained by harvesting a 76 cm by 4 m swath from each plot using a plot combine.

Since rice seeding rate was constant, creeping rivergrass measurements were also recorded to determine if the varying densities of creeping rivergrass impacted biomass and reproductive potential. Fresh weight, number of nodes, number of stolons, total length of stolons, and number of panicles produced were determined from four randomly selected creeping rivergrass plants from each plot 1 day prior to permanent flood removal. Plant assessments were performed as previously described. Data were analyzed using SAS as described for the rice planting rate study with creeping rivergrass planting density as treatments.

Temperature Study. A study was conducted in the growth chamber at Louisiana State University in Baton Rouge, Louisiana to asses the effects of constant temperature on creeping rivergrass vegetative germination. The growth chamber was maintained at a relative humidity of 50 ± 10%. Light was provided by overhead 17-watt fluorescent bulbs with a minimum intensity of 169 µmols/m^2/s photosynthetic photon flux set for a light-dark regime of 12:12 h. Constant temperatures of 11, 15, 19, 23, 27, and 31 C were evaluated. The temperatures were based on monthly average air temperatures for south Louisiana (LOSC 2008). Each temperature regime was evaluated individually because of a limited number of growth chambers. Creeping rivergrass stolon segments obtained from the aforementioned greenhouse stock were cut into 8-cm segments containing one mature vegetative node. Nodes were considered mature if located at least two nodes from the growing point of each stolon.

The study was a completely randomized design with four replications. Each replication consisted of 100, 8-cm single node segments planted into 28 by 48 cm growing flats with 27-cm^3 planting cells. The stolon segments were placed in each planting cell vertically into the soil so that the node was covered by 2 cm of commercial potting soil[1]. Immediately after planting, each growing flat was placed in a larger 2 cm deep tray to allow for sub-irrigation. The sub-irrigation trays were filled to maximum capacity daily. Growing flats were rotated within the growth chamber to account for possible small temperature and lighting differences between shelves.

Germination was evaluated at 7, 10, 14 and 21 days after planting. A node was considered germinated when shoots were 2-mm. Because no change in emergence was observed from 14 to 21 days after planting only germination data for 7, 10, and 14 days were analyzed.

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[1]Jiffy Mix Grower's Choice. Jiffy Products of America, Inc., 5401 Baumhart Rd., Lorain, Ohio 44053.

Data were arranged as repeated measures and were analyzed using the Mixed Procedure of SAS (SAS 2008) with run, rep(run), and temperature*rep(run) as random factors. Type III statistics were used to test all possible effects of fixed factors (germination) and least square means were used for mean separation at a 5% probability level ($p \le 0.05$).

Results and Discussion

Rice Seeding Rate Study. For each creeping rivergrass growth parameter, data for various rice seeding rates were compared with the control where rice was not planted. As rice density increased from 23 to 112 kg/ha, creeping rivergrass fresh weight and total stolon production increased ($P \le 0.05$) compared with the control (Table 3.1). However, there was no difference in total stolon length and node production when the control was compared with 23 kg/ha seeding rate. These results indicate that an adequate rice stand can reduce the ability of creeping rivergrass to re-establish. Creeping rivergrass fresh weight decreased 40 g/plant when rice was seeded at 23 kg/ha and 90 to 110 g/plant at seeding rates of 45 kg/ha or more (Table 3.1). Fresh weight was reduced 38% more when rice was planted at 45 kg/ha compared with 23 kg/ha. Total stolon length decreased 860 to 990 cm at rice seeding rates of at least 45 kg/ha.

Stolon production for creeping rivergrass grown without competition averaged 34 per plant; stolon production was 15 to 13 per plant at rice seeding rates of 45 to 112 kg/ha (Table 3.1). Stolon production was reduced 35% more when rice was planted at 45 kg/ha compared with 23 kg/ha. Node production for creeping rivergrass in monoculture averaged 190 per plant and was reduced to 120 to 100 per plant where rice was seeded at 45 kg/ha or more (Table 3.1). In this study the ability of creeping rivergrass to produce above ground biomass was greatly limited when grown in competition with rice. At a rice seeding rate of 45 kg/ha, fresh weight, total stolon length, stolon production, and node production was reduced 53, 44, 56, and 37%, respectively, when compared with creeping rivergrass grown in monoculture. Increasing rice seeding rate more than 45 kg/ha did not further reduce the ability of creeping rivergrass to re-establish.

Table 3.1. Creeping rivergrass fresh weight, stolon length, stolon production, node production as affected by rice seeding rate at Louisiana State University AgCenter Rice Research Station near Crowley, Louisiana 2006, 2007, and 2008.[a]

Rice planting rate	Rice planting rate (kg/ha)					Estimated mean
	23	45	67	90	112	
	Fresh Weight					
— kg/ha —	P value					— g/plant —
0	0.0484	<0.0001	<0.0001	<0.0001	<0.0001	170 a
23		0.0060	0.0030	0.0004	0.0004	130 b
45			0.8586	0.4022	0.4274	80 c
67				0.4988	0.5280	70 c
90					0.9636	60 c
112					-	60 c
	Stolon Length					
						— cm —
0	0.2063	0.0002	<0.0001	<0.0001	<0.0001	1960 a
23		0.0099	0.0048	0.0008	0.0013	1690 a
45			0.8419	0.4397	0.5307	1100 b
67				0.5564	0.6611	1060 b
90					0.8805	940 b
112					-	970 b
	Stolon Production					
						- no./plant -
0	0.0024	<0.0001	<0.0001	<0.0001	<0.0001	34 a
23		0.0131	0.0193	0.0030	0.0028	23 b
45			0.8362	0.6389	0.6259	15 c
67				0.4898	0.4782	15 c
90					0.9851	13 c
112					-	13 c
	Node Production					
						- no./plant -
0	0.3810	0.0046	0.0018	0.0003	0.0007	190 a
23		0.0410	0.0197	0.0047	0.0084	170 a
45			0.7992	0.4317	0.5645	120 b
67				0.5852	0.7415	120 b
90					0.8286	100 b
112					-	110 b

[a]P-values included for all two-way comparisons of rice planting rates. For estimated means, means followed by the same letter do not significantly different at p=0.05.

The recommended rice seeding rate for drill-seeded and water-seeded rice is 67 to 100 kg/ha and 100 to 140 kg/ha, respectively (Anonymous 2007).

In this study and the creeping rivergrass density study the rice was drill-seeded. Drill-seeding provides for more uniformity in seed distribution and provides an environment less conducive to creeping rivergrass, which thrives under aquatic conditions (Baruch 1994; Bottoms et al. 2009). In south Louisiana drill-seeding is not always an option due to the weather conditions and water-seeding is widely practiced (Saichuk 2008). Regardless of planting system a uniform rice stand would be critical to providing rice with a competitive advantage over creeping rivergrass. Recently there has been a trend to use lower rice seeding rates, 30 to 60 kg/ha, in order to decrease seed cost, especially in herbicide-resistant cultivars and hybrids (Saichuk 2008). Since herbicides alone are not effective in controlling creeping rivergrass, seeding rates of at least 45 kg/ha should be used in drill-seeded culture to reduce competitiveness and reproductive ability of creeping rivergrass.

Creeping Rivergrass Density Study. Growth and yield parameters for rice grown with creeping rivergrass at various planting densities were compared with rice grown in monoculture (weed-free). As creeping rivergrass density increased from 13 to 52 plants/m^2, rice height decreased at least 5 cm compared with the weed-free control (Table 3.2). Rice panicle and stem production were not affected by creeping rivergrass competition. Compared with the weed-free, rice grain yield was decreased 17 and 29% only for creeping rivergrass densities of 26 and 52 plants/m^2, respectively. Since panicle production was not affected by creeping rivergrass competition it is assumed that yield reduction was attributed to fewer seeds/panicle and/or reduced seed weight, but this was not measured.

Compared with research on barnyardgrass, where similar planting densities were used as in the current study (Valverde et al. 2001) creeping rivergrass appears less competitive with rice. This difference could be due to the growth habit of creeping rivergrass. Barnyardgrass is an annual and does not produce stolons. Stolon production allows creeping rivergrass to be

Table 3.2. Rice height, panicle production, stem production, and yield as affected by creeping rivergrass planting density at Louisiana State University AgCenter Rice Research Station near Crowley, Louisiana, 2006 and 2007.[a,b]

Creeping rivergrass density	Creeping rivergrass density (plants/m^2) 1	3	7	13	26	52	Estimated mean
	Rice height						
– plants/m^2 –	P value						— cm —
0	0.4443	0.4785	0.8646	0.0157	0.0102	0.0076	90 a
1		0.9547	0.3506	0.0883	0.0621	0.0486	89 ab
3			0.3803	0.0787	0.0550	0.0429	89 ab
7				0.0102	0.0066	0.0048	91 a
13					0.8646	0.7763	85 bc
26						0.9095	84 c
52						-	84 c
	Rice panicle production						
							— no./m^2 —
0	0.4434	0.1099	1.000	0.3081	0.3644	0.0156	480 a
1		0.3948	0.4434	0.7977	0.8668	0.0878	450 a
3			0.1099	0.5505	0.4777	0.3794	400 a
7				0.3081	0.3644	0.0156	480 a
13					0.9093	0.1437	430 a
26						0.1160	450 a
52						-	360 a
	Rice stem production						
							— no./m^2 —
0	0.5111	0.2433	0.8140	0.2623	0.4121	0.0267	550 a
1		0.6053	0.6722	0.6384	0.8692	0.1099	500 a
3			0.3492	0.9625	0.7243	0.2723	470 a
7				0.3735	0.5572	0.0457	530 a
13					0.7598	0.2527	480 a
26						0.1497	490 a
52						-	400 a
	Rice grain yield						
							— kg/ha —
0	0.1601	0.0577	0.1090	0.1202	0.0027	<0.0001	5070 a
1		0.6051	0.8368	0.8767	0.0866	0.0003	4670 ab
3			0.7553	0.7171	0.2241	0.0015	4530 ab
7				0.9595	0.1292	0.0006	4610 ab
13					0.1174	0.0005	4630 ab
26						0.0365	4190 b
52						-	3590 c

[a]P-values included for all two-way comparisons of rice planting rates. For estimated means, means followed by the same letter are not significantly different at p=0.05.
[b]Rice seeding rate of 100 kg/ha

more opportunistic and adaptable. Stolons grow along the ground and new plants arise in areas with less competition. The lack of effect on rice grain yield may contribute to the spread of creeping rivergrass. Since yield losses do not occur at low densities, producers tend to neglect creeping rivergrass until density is very high and is greatly impacting rice yields or interfering with a cultural practice such as crawfish harvest or tillage (Saichuk 2008). As infestation of creeping rivergrass increases, further movement of stolons by tillage equipment and irrigation waters increase the opportunity for spread. Once established at high populations, creeping rivergrass is very difficult to manage using cultural or chemical methods in a rice production system (Griffin et al. 2008; Webster et al. 2007).

In addition to documenting the impact of creeping rivergrass on rice yield and growth, this research also allowed for investigation of the effect of creeping rivergrass intraspecific competition. When rice was planted at the recommended seeding rate of 100 kg/ha, creeping rivergrass fresh weight, total stolon length, and node production were not affected by planting density (Table 3.3). As creeping rivergrass planting density increased from 13 to 52 plants/m^2 panicle production increased ($p \leq 0.05$) compared with 1 or 3 plants/m^2 (Table 3.3). This response, although significant, may not be of practical significance because previous research has shown that creeping rivergrass seed production averages only 0.7 seeds/panicle (Bottoms et al. 2006).

Temperature Study. At 7 days after creeping rivergrass stolon segments were planted, shoot initiation (emergence) decreased from 98% at a constant temperature of 31 C to no more than 2% at constant temperatures of 15 and 11 C (Table 3.4). At both 10 and 14 days, emergence was greatest and at least 97% when temperature was 27 or 31 C. Emergence decreased as temperature decreased and by 14 days emergence was 2% for 11 C and 23% for 15 C.

Table 3.3. Creeping rivergrass fresh weight stolon length, node production as affected by creeping rivergrass planting density at Louisiana State University AgCenter Rice Research Station near Crowley, Louisiana, 2006 and 2007.[a,b]

Creeping rivergrass density	Creeping rivergrass density ($plants/m^2$) 3	7	13	26	52	Estimated mean
	Fresh weight					
– $plants/m^2$ –	P value					— g/plant —
1	0.0722	0.1758	0.9760	0.1729	0.8040	172 a
3		0.6273	0.0590	0.6242	0.0055	111 a
7			0.1525	0.9972	0.2489	127 a
13				0.1498	0.7752	173 a
26					0.2450	126 a
52					-	164 a
	Stolon length					
						— m/plant —
1	0.0389	0.2222	0.8699	0.8897	0.5736	21 a
3		0.3364	0.0230	0.0454	0.0087	12 a
7			0.1537	0.2608	0.0693	16 a
13				0.7541	0.6788	22 a
26					0.4683	21 a
52					-	24 a
	Node production					
						— no./plant —
1	0.0283	0.0652	0.6879	0.1676	0.2821	81 a
3		0.6481	0.0091	0.3456	0.2114	56 a
7			0.0224	0.6107	0.4053	53 a
13				0.0687	0.1300	88 a
26					0.7442	61 a
52					-	65 a
	Panicle production					
						— no./plant —
1	0.6199	0.8343	0.0004	0.0548	0.0107	11 bc
3		0.4653	<0.0001	0.0192	0.0021	10 bc
7			0.0005	0.0736	0.0192	11 c
13				0.0543	0.2179	18 a
26					0.4653	15 ab
52					-	16 a

[a]P-values included for all two-way comparisons of rice planting rates. For estimated means, means followed by the same letter are not significantly different at p=0.05.
[b]Rice seeding rate of 100 kg/ha

Table 3.4. Shoot initiation of stolon segments as affected by constant temperature regimes 7, 10 and 14 days after planting in growth chambers at Louisiana State University.[a,b]

Constant temperature	Days after planting 7	10	14
C	% emergence		
11	0 e	2 e	2 e
15	2 e	18 d	23 d
19	31 d	55 c	57 c
23	67 c	77 b	78 b
27	83 b	97 a	97 a
31	98 a	98 a	98 a

[a]Means followed by the same letter are not significantly different at p=0.05.

LSU AgCenter recommends rice planting when average daily temperatures are above 13 C (Anonymous 2007). In the temperature study shoot initiation in creeping rivergrass stolons was 23% at a constant temperature of 15 C. An average daily temperature of 15 C would correspond to conditions in early March in Acadia Parish, which falls near the early rice planting date of March 15 recommended by the LSU AgCenter. Results suggest that early planting of rice could provide a competitive advantage by allowing rice to establish earlier than creeping rivergrass.

Since chemical control methods in rice for creeping rivergrass have not provided acceptable control, an integrated weed management approach using cultural and chemical control measures should be considered. Results show that ability of creeping rivergrass to establish is reduced when rice seeding rate is at least 45 kg/ha in drill-seeded rice. Recommended seeding rates for drill-seeded rice is 67 to 100 kg/ha (Anonymous 2007). Creeping rivergrass thrives under aquatic conditions. Although not evaluated in this study it would be assumed that high rice seeding rate in water-seeding (100 to 140 kg/ha) would also enhance the competitiveness of rice. This research highlights the importance of rice stand uniformity in management of creeping rivergrass regardless of seeding method. This finding is substantiated in the creeping rivergrass density study where rice was planted at 100 kg/ha. At this rice seeding rate creeping rivergrass density as high as 52 plants/m^2

did not negatively effect rice stem or panicle production. In respect to yield a creeping rivergrass density of 26 plants/m^2 was needed to reduce yield. Time of rice planting can also be used as a control method. Planting rice in early March is conducive to rice seed germination but not to creeping rivergrass node germination and establishment. Use of standard chemical control measures, high seeding rate, and early planting can provide rice the competitive advantage over creeping rivergrass.

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Chapter 4

Effects of Herbicides on Growth and Vegetative Reproduction of Creeping Rivergrass

Creeping rivergrass [*Echinochloa polystachya* (Knuth) Hitch.] is an aquatic perennial C_4 grass presently infesting 5,000 to 6,000 hectares of rice (*Oryza sativa* L.) and crawfish production in south Louisiana (Saichuk 2008). Creeping rivergrass is an adaptable, aggressive weed that is difficult to control in rice culture in south Louisiana (Bottoms et al. 2009). The sub-tropical climate of this region and management practices associated with rice and crawfish production are conducive to the colonization of creeping rivergrass.

Currently, creeping rivergrass can not be controlled with herbicides alone (Webster 2009). The management program must include a fallow period and cultivation, along with a herbicide program that includes high rates of glyphosate (Bottoms et al. 2009). In rice cyhalofop[1] at 208 g ai/ha early postemergence (EPOST) followed by (fb) 315 g/ha late postemergence (LPOST) or imazethapyr[2] at 70 g ai/ha very early postemergence (VEPOST) fb 70 g/ha LPOST controlled creeping rivergrass 85% (Webster et al. 2007). Bispyribac[3] at 22 g ai/ha EPOST fb 22 g/ha LPOST, fenoxaprop[4] at 66 g ai/ha EPOST fb 86 g/ha LPOST, and penoxsulam[5] at 50 g ai/ha MPOST resulted in at least 65% control. When data were averaged across herbicide treatments creeping rivergrass control was 81 to 84% 7 to 21 DAT, 77% at 28 DAT, and 63% at 49 days after treatment (DAT), indicating regrowth occurred as the season progressed.

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[1]Clincher® SF herbicide label. Dow AgroScience, Indianapolis, IN 46268.
[2]Newpath® herbicide label. BASF Corporation, Research Triangle Park, NC 27709.
[3]Regiment™ herbicide label. Valent Corp., Walnut Creek, CA 94596
[4]Whip® 360 herbicide label. Bayer CropScience, P.O. Box 12014, 2 T.W. Alexander Dr., Research Triangle Park, NC 27709.
[5]Grasp® herbicide label. BASF Corporation, Research Triangle Park, NC 27709.

A glasshouse study evaluated the activity of the following herbicides: bispyribac at 22 g/ha; cyhalofop at 314 g/ha; fenoxaprop/s[6] at 86 g/ha; fenoxaprop/s at 46 g/ha plus fenoxaprop at 40 g/ha; glufosinate[7] at 497 g ai/ha; glyphosate[8] at 1260 g ae/ha; imazethapyr at 70 g/ha; penoxsulam at 50 g/ha; propanil[9] at 3364 g ai/ha; and quinclorac[10] at 560 g ai/ha (Griffin et al. 2008). Cyhalofop, glyphosate, glufosinate, imazethapyr, fenoxaprop/s, and penoxsulam reduced fresh weight 25 to 50% at 14 DAT and 63 to 80% at 28 DAT compared with the nontreated. Propanil reduced fresh weight 25% at 14 DAT and 20% at 28 DAT compared with the nontreated, indicating regrowth; however, quinclorac increased fresh weight by 24% compared with the nontreated. Use of propanil and quinclorac is not recommended for control of creeping rivergrass and in some cases the use of quinclorac may encourage growth.

The previously mentioned field and glasshouse studies evaluated herbicides on plants grown from 7-cm single node stolon segments, which mimicked the effects of multiple tillage operations in a fallow field. In south Louisiana rice fields, a single creeping rivergrass plant can form 100,000 stolons/ha measuring a total length 33 km/ha (Griffin et al. 2008).

Stolons, leaves, and roots of creeping rivergrass are capable of storing large amounts of nutrients (Piedade et al. 1997). In the nutrient-rich waters of the Amazon floodplain, nitrogen and phosphorus concentrations were found to be highest in the leaves with a peak N concentration of 24 g/kg when the flood was deepest, and a P concentration of 1.5 to 1.9 g/kg (Pompeo

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[6]Ricestar HT® herbicide label. Bayer CropScience, P.O. Box 12014, 2 T.W. Alexander Dr., Research Triangle Park, NC 27709.
[7]Ignite® herbicide label. Bayer CropScience, P.O. Box 12014, 2 T.W. Alexander Dr., Research Triangle Park, NC 27709.
[8]Roundup WeatherMax® herbicide label. Monsanto Co., St. Louis, MO 63167.
[9]Stam® M4 herbicide label. Dow AgroScience, Indianapolis, IN 46268.
[10]Facet® herbicide label. Dow AgroScience, Indianapolis, IN 46268.

et al. 1999). The greatest C concentration, up to 463 mg/gDW, was found in the stem. However, the root C concentration did reach 452 mg/gDW.

Not only do the plants store large concentrations of nutrients, but as plant material senesces, a portion of N and P is redistributed to the growing points and the relative share of C in live biomass increases. Because of the ability of creeping rivergrass to sequester large amounts of nutrients, particularly C in stolons, plants growing from longer stolon segments or rhizomes may be less sensitive to herbicides.

In addition to large amounts of above ground biomass production in rice fields, creeping rivergrass also produces ginger-like rhizomes (Urbatsch 2009). Two types of rhizome structures have been observed in rice fields with dense populations, single rhizome segments and highly developed multi-rhizome clusters (Urbatsch 2009). The rhizome segments are more commonly associated with young plants. As the plants mature, the more highly developed multi-rhizome cluster is formed. These structures are not mentioned in other research studies, most of which were conducted in the Amazon flood basin. It is possible that these structures are more prevalent in the shallow flood situations of rice fields and that they may store larger concentrations of nutrients than stolon, leaves, or roots. However, there are no documented cases to support these theories.

The objectives of this research is to indentify effects of common rice herbicides on creeping rivergrass growth and vegetative reproductive potential on plants grown from: 1) single-node stolon segments; 2) longer multi-node stolon segments; 3) rhizome segments and clusters.

Materials and Methods

Single-node Stolon Segments. A glasshouse study was conducted at Louisiana State University to determine the impact of rice herbicides and glyphosate on the growth and reproductive potential of creeping rivergrass in 2007. The experimental design was completely randomized with a six by two factorial arrangement with four replications. The study was repeated. Factor A consisted of six herbicide treatments: cyhalofop at 314 g/ha, glyphosate at 1121 g/ha, imazethapyr at 105 g/ha, penoxsulam at 49 g/ha, quinclorac at 556 g/ha, and a nontreated for comparison. Factor B was replant timing of nodes harvested from treated plants at 14 or 28 DAT.

Pots measuring 3.75 L in capacity, 20 cm in diameter and 17 cm in height, were filled with a 50:50 mixture of a sterilized Commerce silt loam (fine-silty, mixed, superactive, nonacid, thermic Aeric Fluvaquent) with less than 0.1% organic matter, 80% sand, 6% silt, 14% clay, and pH 7.0 and potting soil[11]. Stolons were harvested from planting stock grown in a glasshouse as previously described by Griffin et al. (2008). The glasshouse was maintained at a diurnal regime of 30:25 ± 5 C and 60 ± 10% rH for the first run and 25:20 ± 5C and 60 ± 10% rH for the second run. Day length was extended to 14 h with metal halide lamps at a minimum intensity of 270 $\mu mols^2/s$ photosynthetic photon flux. The stolons were cut into 7-cm single node segments. Two segments were planted in each pot at a depth of 2 cm. After seven days one of the segments was removed from each pot to ensure uniform plant size. The pots were placed in 61- by 89- by 23-cm trays for sub-irrigation in which a water depth of 3 cm was maintained daily. At 8 DAP stolon and leaf counts were recorded and measurements of stolons produced per plant were summed to quantify total stolon length. Herbicide treatments were applied 8 DAP to three to four leaf plants.

Plants were harvested at their appropriate timing after treatment, factor B. The plants were removed from the pots and the soil was washed from the roots. Excess water on the plants was removed by blotting with a paper towel and allowing plants to air dry for 30 minutes prior to weighing. Whole plants were weighed and the above ground portion was measured and cut into 7-

[11]Jiffy Mix Grower’s Choice. Jiffy Products of America, Inc., 5401 Baumhart Rd., Lorain, Ohio 44053.

cm single node stolon segments. Nodes were counted and the segments were planted in 28 by 48 cm growing flats consisting of 27 cm^3 planting cells to determine node viability. Emergence was monitored and recorded daily for 14 d.

Data were analyzed using the Mixed Procedure of SAS (SAS Institute 2006) with run used as a random factor due to differences in glasshouse temperature between the two runs. Run, replication (nested within run), and all interactions containing either of these effects were considered random effects; treatment was considered a fixed effect. Considering runs or combination of runs as random effects permits inferences about treatments over a range of environments (Carmer et al. 1989). Type III statistics were used to test all possible effects of fixed factors (growth parameters) and least square means were used for mean separation at a 5% probability level ($p \leq 0.05$).

Multi-node Stolon Segments. A glasshouse study was conducted to evaluate the effect of herbicides on the growth and vegetative reproductive potential of creeping rivergrass plants grown from various length multi-node stolon segments in 2008. The experimental design was completely randomized with a four by four by two factorial arrangement with three replications. The study was repeated. Factor A consisted of four herbicide treatments: imazethapyr at 105 g/ha, cyhalofop at 314 g/ha, glyphosate at 1121 g/ha, and a nontreated for comparison. Factor B was the length of the multi-node stolon segments from which the plants were grown. Plants were grown from either: 7-cm, single node stolon segment; 15-cm, two-node stolon segment; 30-cm, four-node stolon segment; or 46-cm, eight-node stolon segment. Factor C was herbicide application timing at 14 or 28 DAP.

The glasshouse was maintained at a diurnal regime of 30:25 ± 5 C and 60 ± 10% rH for the first run and 25:20 ± 5 C and 60 ± 10% rH for the second run. Day length was extended to 14 h with metal halide lamps at a minimum intensity of 270 µmols^2/s photosynthetic photon flux. Stolons were harvested from stock plant material as previously described and cut to the various multi-node lengths. Because the segments were different lengths pot size was based on approximately 80 cm^2 of surface area per node, corresponding to the following pot sizes: 10, 15, 21, and 30 cm diameter pots. The soil used was a 50:50 blend of Commerce silt loam and potting soil as previously described. Stolon segments were planted at a depth of 2 cm. The pots were placed in trays as previously described for sub-irrigation.

Plants were measured and shoot counts were recorded at the designated herbicide application timing of either 14 or 28 DAP. AT 14 DAT, plants were removed from pots as previously described and whole plants were weighed. The above ground portion was measured and cut into 7-cm single node stolon segments. Nodes were counted and the segments were planted growing flats as previously described to determine node viability. Emergence was monitored and recorded daily for 14 d. Data were analyzed using the Mixed procedure in SAS, previously described.

Rhizome Structures. A glasshouse study was conducted to evaluate the effect of herbicides on the growth and vegetative reproductive potential of creeping rivergrass plants grown from rhizomes in 2008. The experimental design was completely randomized with a four by two by two factorial arrangement with three replications. The study was repeated. Factor A consisted of four herbicide treatments: imazethapyr at 105 g/ha, cyhalofop at 314 g/ha, glyphosate at 1121 g/ha, and a nontreated for comparison. Factor B was parent structure type, a rhizome segment or rhizome cluster, from which the plants were grown. Factor C was herbicide application timing of 14 or 28 DAP.

Rhizome structures were harvested from a natural stand near Kaplan, Louisiana. Whole plants were removed from wet soil, the aerial portion removed and the rhizome/root section placed in plastic bags for transport.

The root sections were stored 14 h in a cooler maintained at 10 C then removed from the bags and separated based on structure type. Rhizome segments were defined as clearly discernable ginger-like rhizomes approximately 5 cm in length. Rhizome clusters were defined as a more highly developed, intertwined, multi-rhizome root structure in which individual rhizomes could not be discerned without breaking the structure apart. Rhizome clusters averaged 200 g and rhizome segments averaged 5 g. Each structure was weighed and sorted into replications based on their weight. Within replication structures were randomly assigned to treatments. One structure was planted per 3.79 L pot, 20 cm diameter and 17 cm in height, in the previously described soil mixture of Commerce silt-loam and potting soil.

The glasshouse was maintained at a diurnal regime of 30:25 ± 5 C and 60 ± 10% rH for the first run and 25:20 ± 5 C and 60 ± 10% rH for the second run. Day length was extended to 14 h with metal halide lamps at a minimum intensity of 270 $\mu mols^2/s$ photosynthetic photon flux. Plants were measured and shoot counts were recorded at the designated herbicide application timing of either 14 or 28 DAP. At 14 DAT plants were removed from pots as previously described and whole plants were weighed. The above ground portion was measured and cut into 7-cm single node stolon segments. Nodes were counted and node viability was assessed as previously described. Emergence was monitored and recorded daily for 14 d. Data were analyzed using the Mixed procedure in SAS as previously described.

Results and Discussion

Single-node Stolon Segments. Analyses indicated that there was no herbicide by timing interaction. All herbicide treatments except quinclorac reduced fresh weight, stolon production and stolon length compared with the nontreated (Table 4.1). In most cases quinclorac did not differ from the nontreated. Griffin et al. (2008) reported similar results with quinclorac. Penoxsulam reduced fresh weight 48% compared with 25 g/plant in the nontreated. However, cyhalofop, glyphosate and imazethapyr reduced fresh weight to less than 16% of the nontreated.

Table 4.1 Effects of herbicides on fresh weight, stolon production, and stolon length of creeping rivergrass plants grown from single-node stolon segments at Louisiana State University Baton Rouge, Louisiana 2007[a,b].

Herbicides	Rate	Fresh weight	Stolons	Stolon length
	g ai/ha		% of nontreated	
cyhalofop	314	4 c	63 b	6 c
glyphosate	1121	4 c	13 c	6 c
imazethapyr	105	16 c	38 c	11 bc
penoxsulam	49	48 b	63 b	46 b
quinclorac	556	108 a	88 a	112 a
nontreated[c]		25 a	8 a	2760 a

[a]Means followed by the same letter do not significantly differ at P=0.05.
[b]Crop oil concentrate, trade name Agri-dex®, Helena Chemical Co., 225 Schilling Boulevard, Suite 300, Collierville, TN 38017 at 1% (v/v) was used with all treatments.
[c]Estimated mean units for the nontreated is as follows: fresh weight, g/plant; stolons, no./plant; and stolon length, cm/plant.

Glyphosate and imazethapyr were the most effective at reducing stolon production to 38% or less of the 8 stolons/plant produced in the nontreated (Table 4.1). Cyhalofop and penoxsulam decreased stolon production to 63% of the nontreated. Glyphosate and imazethapyr have the greatest potential for decreasing plant growth of creeping rivergrass produced from single-node stolon segments.

Reduced fresh weight and stolon production suggests an overall reduction in biomass which is supported by the decrease in stolon length of 2760 cm/plant in the nontreated to 46% of the nontreated by penoxsulam and 11% or less of the nontreated by cyhalofop, glyphosate, and imazethapyr Table 4.1). The use of penoxsulam can reduce overall biomass production by approximately 50%; however, cyhalofop, glyphosate, and imazethapyr can reduce biomass production by more than 80%.

Decreased stolon length reduces the amount of nodes that were produced. Node production and adventitious root formation directly impacts colonization rate. Penoxsulam decreased node and adventitious root formation to 39 and

27% of the nontreated, respectively (Table 4.2). However, cyhalofop, glyphosate, and imazethapyr had the largest negative impact on colonization rate by reducing node production to less than 12% of the nontreated and adventitious root formation to 0% of the nontreated.

Table 4.2. Effects of herbicides on node production, adventitious root formation, germination of treated nodes and stolon length of creeping rivergrass plants grown form single-node stolon segments at Louisiana State University, Baton Rouge, Louisiana 2007[a,b].

Herbicides	Rate	Nodes	Adventitious roots	Germination	Stolon length
	g ai/ha		% of nontreated		
cyhalofop	314	4 c	0 b	0 d	0 b
glyphosate	1121	4 c	0 b	0 d	0 b
imazethapyr	105	12 c	0 b	40 c	8 b
penoxsulam	49	39 b	27 b	72 b	29 b
quinclorac	556	104 a	91 a	93 a	85 a
nontreated[c]		26 a	11 a	85 a	2680 a

[a]Means followed by the same letter do not significantly differ at P=0.05.
[b]Crop oil concentrate, trade name Agri-dex®, Helena Chemical Co., 225 Schilling Boulevard, Suite 300, Collierville, TN 38017 at 1% (v/v) was used with all treatments.
[c]Estimated mean units for the nontreated is as follows: nodes and adventitious roots, no./plant; germination, %; and stolon length, cm/plant.

Decreases in the viability of nodes produced by treated plants would reduce population growth. Cyhalofop, glyphosate, and imazethapyr had the greatest impact on viability of nodes from treated plants and the subsequent growth (Table 4.2). Imazethapyr reduced germination of nodes from treated plants to 40% of the nontreated; whereas, cyhalofop and glyphosate reduced germination of these nodes to 0% of the nontreated. However, subsequent growth of nodes from treated plants was reduced to less than 30% of the nontreated with cyhalofop, glyphosate, imazethapyr, and penoxsulam. There were no differences between quinclorac and the nontreated for node production, adventitious root formation, or germination and growth of nodes from treated plants.

Because quinclorac did not reduce creeping rivergrass node number, adventitious root formation and germination of nodes from treated plants it should not be used as part of a herbicide program for creeping rivergrass. Although penoxsulam did not decrease growth and reproductive potential as much as cyhalofop, glyphosate and imazethapyr, it could be used in a herbicide program for fields containing creeping rivergrass. Cyhalofop is approved for use with all rice varieties and should be considered when developing a herbicide program for creeping rivergrass. Imazethapyr can only be used in conjunction with Clearfield rice varieties or hybrids which are resistant to the imidazolinone family of herbicides. The use of Clearfield varieties along with imazethapyr is recommended when managing creeping rivergrass. Although glyphosate can not be used in-crop, use as a burndown herbicide could prove important when developing a creeping rivergrass management plan.

Creeping rivergrass plants in this study were initiated from short single-node stolon segments. In many field situations creeping rivergrass germinates from long, multi-node stolons. Plants growing from long stolon segments may be more robust and less sensitive to herbicide treatments.

Multi-node Stolon Segments. Analyses indicated there was no herbicide by node number by timing interaction. The use of cyhalofop, glyphosate, and imazethapyr can reduce the competitiveness of creeping rivergrass with rice by decreasing the biomass produced, which is indicated by a reduction in fresh weight to less than 26% of the nontreated (Table 4.3). Glyphosate, cyhalofop, and imazethapyr can reduce growth and competitiveness of creeping rivergrass produced from multi-node stolon segments, regardless of timing of application.

Stolon production was reduced to less than 39% of the nontreated regardless of application timing (Table 4.3). Reduced stolon production indicates a reduction in biomass and reduced node production potential of creeping rivergrass plants produced from multi-node stolon segments.

Table 4.3 Effect of herbicides stolon production, stolon length fresh weight, node production and germination of creeping rivergrass grown from multi-node stolon segments at Louisiana State University, Baton Rouge, Louisiana in 2008, averaged over length and timing[a,b].

Herbicide treatment	Rate	Fresh weight	Stolons	Stolon length	Nodes	Germination
	g ai/ha	———	———	% of nontreated	———	———
cyhalofop	314	26 a	39 a	21 a	23 a	35 a
glyphosate	1121	13 c	22 b	14 b	19 a	7 b
imazethapyr	105	19 b	34 b	16 b	20 a	26 a
nontreated[c]		68 a	691 a	86 a	18 a	48 a

[a]Means followed by the same letter do not significantly differ at P=0.05.
[b]Crop oil concentrate, trade name Agri-dex®, Helena Chemical Co., 225 Schilling Boulevard, Suite 300, Collierville, TN 38017 at 1% (v/v) was used with all treatments.
[c]Estimated mean units for the nontreated is as follows: nodes and stolons, no./plant; stolon length, cm/plant; fresh weight, g/plant; germination, %.

Overall plant length was reduced to less than 21% of the nontreated, regardless of timing of application (Table 4.3). The reduction of stolon length of creeping rivergrass plants grown from multi-node stolon segments indicates the use of glyphosate, cyhalofop, and imazethapyr can decrease stolon growth 68 to 74 cm/plant which directly relates to a decrease in node production.

Node production was reduced to less than 23% of the nontreated regardless of timing of application (Table 4.3). Reduced node production from creeping rivergrass plants grown from multi-node stolon segments indicates reduced colonization potential. Germination of nodes from treated plants was reduced to less than 35% of the nontreated regardless of timing of application. The reduction could directly impact colonization rate and population growth.

Results indicate that cyhalofop, glyphosate, and imazethapyr are effective in reducing growth and reproductive potential of creeping rivergrass regardless of nodes per parent stolon. However, plants grown from rhizomes could potentially be more vigorous plants than those growing from stolon segments. Although not found in the literature, rhizomes potentially have more carbohydrate reserves than stolons. Plants grown from a rhizome structure may be able to recover from herbicide injury compared with plants established from stolons.

Rhizome Structures. Analyses indicated that reduction in growth and reproductive parameters were dependent on parent structure type regardless of application timing.

Fresh weight was 54 to 64% of the nontreated, when plants were grown from a rhizome cluster compared with 10 to 31% of the nontreated when plants were grown from a single rhizome segments (Table 4.4). These results suggest that activity of glyphosate, cyhalofop, and imazethapyr may be less when applied to creeping rivergrass plants produced from more highly developed rhizome clusters. Plants grown from rhizome clusters may be more competitive with rice than plants grown from single rhizomes.

Stolon production was 56% of the nontreated with cyhalofop on plants from a single rhizome segments and 84% of the nontreated on plants grown from rhizome clusters. However, stolon production was 44 to 25% of the nontreated with glyphosate and imazethapyr, regardless of parent structure type. All herbicides reduced stolon length to less than 34% of the nontreated regardless of parent structure. Cyhalofop is less effective at reducing stolon production when applied to creeping rivergrass plants grown from more highly developed rhizome clusters. Reduced stolon production reduces the competitiveness of creeping rivergrass with rice.

Node production was reduced to 15% or less of the nontreated with all herbicides regardless of parent structure (Table 4.4). Reduced node production may decrease rate of creeping rivergrass colonization.

Germination of nodes produced from treated plants was 59% and 28% of the nontreated with imazethapyr on plants germinated from rhizome segments and clusters, respectively. Cyhalofop and glyphosate reduced node germination to 19% or less of the nontreated regardless of parent structure.

Reduced node germination could directly impact creeping rivergrass colonization rate.

Table 4.4 Effect of herbicides on growth and reproductive parameters of creeping rivergrass plants grown from different parent root structures as percent of nontreated at Louisiana State University, Baton Rouge, Louisiana in 2008, averaged over timing[a,b].

Herbicide treatment[c]	Parent structure type: rhizome	Parent structure type: rhizome cluster
	— Fresh weight, % of nontreated —	
cyhalofop	31 bc	54 a
glyphosate	10 c	55 a
imazethapyr	15 bc	64 a
nontreated[d]	71 (g) a	472 (g) a
	— Stolon production, % of nontreated —	
cyhalofop	56 b	84 a
glyphosate	25 d	29 d
imazethapyr	44 c	43 c
nontreated	16 (stolons) a	49 (stolons) a
	— Total Length, % of nontreated —	
cyhalofop	18 bc	34 a
glyphosate	11 c	13 c
imazethapyr	16 bc	20 b
nontreated	575 (cm) a	2291 (cm) a
	— Node production, % of nontreated —	
cyhalofop	6 c	10 b
glyphosate	0 d	4 c
imazethapyr	6 c	15 a
nontreated	31 (nodes) a	111 (nodes) a
	— Germination of stolon segments, % of nontreated —	
cyhalofop	5 d	19 c
glyphosate	2 d	10 d
imazethapyr	59 a	28 b
nontreated	64 (%) a	88 (%) a

[a]Means followed by the same letter do not significantly differ at P=0.05.
[b]Crop oil concentrate, trade name Agri-dex®, Helena Chemical Co., 225 Schilling Boulevard, Suite 300, Collierville, TN 38017 at 1% (v/v) was used with all treatments.
[c]Herbicide rates as follows: cyhalofop 314 g/ha; glyphosate 1121 g/ha; imazethapyr 105 g/ha.
[d]Estimated means for the nontreated displayed on a per plant basis.

These results indicate that herbicide activity may decrease on plants grown from highly developed rhizome clusters, suggesting that implementation of a herbicide program would be more effective on younger less established populations. Early implementation of an integrated weed management system that includes tillage would disrupt population establishment increasing the success of the herbicide program.

In conclusion, based on this research, a herbicide program for the management of creeping rivergrass should include glyphosate applied at 1121 g/ha as a burndown treatment. Glyphosate should be utilized throughout the fallow period when tillage is not an option as well as immediately prior to rice planting. A Clearfield rice variety or hybrid should be selected to allow the use of imazethapyr applied at 105 g/ha as an EPOST fb LPOST application. Cyhalofop should be used as needed throughout the season at 314 g/ha. Although residual preemergence herbicides have no activity on creeping rivergrass, the addition of a herbicide, such as clomazone, would help control other weed species, allowing the rice to emerge free of competition from other weeds (Zhang et al. 2005).

Employing an adequate herbicide program coupled with other integrated management strategies such as tillage, early planting, and increased rice seeding rates decreases the competition of creeping rivergrass with rice, reduces total population size and reduces the spread of this weed (Bottoms et al. 2009). The integrated weed management program should be implemented in fields that have established stands of creeping rivergrass until the population of the field, neighboring fields and irrigation water-ways are completely controlled.

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Chapter 5

Summary and Conclusions

This research was conducted to evaluate competition of creeping rivergrass with rice and the effect of temperature, burial depth, desiccation, flood depth, and herbicides on creeping rivergrass growth and vegetative germination. Results from this research will be used to design an integrated management program for creeping rivergrass in rice production.

Results from seed production, germination and seedling vigor studies suggest creeping rivergrass seed production is low and germination of seeds in rice culture would be unlikely. Seedling vigor was poor and plants grown from seeds were male sterile.

Results from flood depth studies suggest establishing a deep flood (≥15 cm) over newly emerging plants could decrease growth and competitiveness of creeping rivergrass with rice. There were no differences in growth between no flood and 15 and 20 cm flood suggesting delayed flood establishment could also reduce biomass and allow rice a competitive advantage over creeping rivergrass.

Although use of no flood and a deep flood for management of creeping rivergrass seem contradictory as a management strategy, these two cultural practices could be readily applied to rice production. Flood depths of most rice fields in Louisiana average 7 to 15 cm after rice is established (Saichuk 2008). Creeping rivergrass usually begins re-growth from previous stolons at the time of rice planting. Dry-seeding rice, weather permitting, is the best option for reducing creeping rivergrass growth and vegetative reproductive ability. However, approximately 50% of the rice in south Louisiana is water-seeded in the pinpoint flood system. This system allows creeping rivergrass to emerge under ideal conditions. Regardless of dry- or water-seeding, permanent flood establishment should be delayed until rice is big enough for deep flooding.

Results from depth of burial studies suggests shallow burial, between 1 and 2.5 cm is ideal for shoot emergence from stolons and rhizomes. Deep burial of stolons, 10 to 20 cm, prevents emergence and renders stolons non-viable. These results suggest fields infested with creeping rivergrass may benefit from repeated deep tillage, to reduce stolon size and to increase burial depth. Shallow tillage may encourage colonization, by increasing germination and viability of vegetative structures. Although germination was poor with no burial, this does not suggest no-till would be beneficial. Stolons segments used in this study were cut to 7 cm in length to mimic fragmenting of multiple tillage operations.

Decreases in biomass production of germinating rhizomes on the soil surface and buried greater than 5 cm indicates deep tillage may reduce growth which decreases the competitiveness of creeping rivergrass with rice. Rresults of two burial depth studies suggest deep tillage resulting in stolon fragmentation and burial greater than 5 cm, and placement of rhizomes on the soil surface may be an important cultural practice in managing creeping rivergrass by reducing colonization and population.

Results from the desiccation study suggests encouraging stolon desiccation to at least 35% of initial fresh weight reduces shoot emergence from stolons. Multiple tillage operations would fragment stolons, accelerating desiccation.

Results from rice and creeping rivergrass competition studies suggest increasing rice seeding rate to at least 45 kg/ha can reduce stolons growth and node production, reducing the competitiveness of creeping rivergrass with rice. The recommended rice seeding rate for drill-seeded and water-seeded rice is 67 to 100 kg/ha and 100 to 140 kg/ha, respectively (Anonymous 2007).

In this study and the creeping rivergrass density study the rice was drill-seeded. Drill-seeding provides for more uniformity in seed distribution and provides an environment less conducive to creeping rivergrass, which thrives under aquatic conditions (Baruch 1994; Bottoms et al. 2009). In south Louisiana drill-seeding is not always an option due to the weather conditions and water-seeding is widely practiced (Saichuk 2008). Regardless of planting system a uniform rice stand would be critical to providing rice with a competitive advantage over creeping rivergrass.

Creeping rivergrass densities of 26 plants/m^2 or more causes rice grain yield loss. Compared with research on barnyardgrass, where similar planting densities were used as in the current study (Valverde et al. 2001) creeping rivergrass appears less competitive with rice. This difference could be due to the growth habit of creeping rivergrass. Barnyardgrass is an annual and does not produce stolons. Stolon production allows creeping rivergrass to be more opportunistic and adaptable. Stolons grow along the ground and new plants arise in areas with less competition. Lack of effect on rice grain yield may contribute to the spread of creeping rivergrass. Since yield losses do not occur at low densities, producers tend to neglect creeping rivergrass until density is very high and is greatly impacting rice yields or interfering with a cultural practice such as crawfish harvest or tillage (Saichuk 2008). As infestation of creeping rivergrass increases, further movement of stolons by tillage equipment and irrigation waters increase opportunity for spread. Once established at high populations, creeping rivergrass is very difficult to manage using cultural or chemical methods in a rice production system (Griffin et al. 2008; Webster et al. 2007).

Results from temperature studies suggests shoot emergence from stolons decrease as temperature decreases from 31 C to 15 and 11 C. LSU AgCenter recommends rice planting when average daily temperatures are above 13 C (Anonymous 2007). In the temperature study shoot initiation in creeping rivergrass stolons was 23% at a constant temperature of 15 C. An average daily temperature of 15 C would correspond to conditions in early March in Acadia Parish, which falls near the early rice planting date of March 15 recommended by the LSU AgCenter. Results suggest that early planting of rice could provide a competitive advantage by allowing rice to establish earlier than creeping rivergrass.

Results of herbicide studies suggest that cyhalofop, glyphosate and imazethapyr are most effective at reducing creeping rivergrass growth, node production and shoot emergence from nodes of treated plants. Herbicide activity may decrease on plants grown from highly developed rhizome clusters, suggesting that implementation of a herbicide program would be more effective on younger less established populations. Early implementation of an integrated weed management system that includes tillage would disrupt population establishment increasing the success of the herbicide program.

A herbicide program for the management of creeping rivergrass should include glyphosate applied at 1121 g/ha as a burndown treatment. Glyphosate should be utilized throughout the fallow period when tillage is not an option as well as immediately prior to rice planting. A Clearfield rice variety or hybrid should be selected to allow the use of imazethapyr applied at 105 g/ha as an EPOST fb LPOST application. Cyhalofop should be used as needed throughout the season at 314 g/ha. Although residual preemergence herbicides have no activity on creeping rivergrass, the addition of a herbicide, such as clomazone, would help control other weed species, allowing the rice to emerge free of competition from other weeds (Zhang et al. 2005).

Management of creeping rivergrass is difficult due to ideal growing conditions and lack of activity of rice herbicides on mature established populations (Webster 2009). Creeping rivergrass requires an integrated management approach (Bottoms et al. 2009). Based on this research the first step in managing creeping rivergrass in rice requires the affected field to be fallow for at least one year. During the fallow period the field should be tilled multiple times to encourage fragmentation of stolons and rhizomes. Deep tillage operations should be conducted whenever possible to bury fragmented stolons and to bring rhizome fragments to the surface to increase desiccation. Burial of stolon segments and desiccation of rhizome segments reduces vegetative germination which reduces the rate of colonization. When an affected field returns to rice production glyphosate at 1121 g/ha should be used as a burndown to reduce growth of newly germinating creeping rivergrass plants. Rice should be seeded as early as possible to allow a competitive advantage over creeping rivergrass. A preemergence application of clomazone should be used to control other weed species and allow rice to emerge free of competition. Rice should be seeded at a seeding rate greater than 45 kg/ha. Increasing seeding rate increases competition of rice with creeping rivergrass. Choosing a Clearfield rice variety or hybrid allows the use of imazethapyr during the growing season. Imazethapyr should be applied at 105 g/ha as an EPOST fb LPOST application. Cyhalofop at 314 g/ha should be used as needed throughout the season. Establishment of permanent flood should be delayed until rice is large enough to survive in a deep flood.

Employing an adequate herbicide program coupled with other integrated management strategies such as tillage, early planting, and increased rice seeding rates decreases the competition of creeping rivergrass with rice, reduces total population size and reduces the spread of this weed (Bottoms et al. 2009). The integrated weed management program should be implemented indefinitely in fields that have established stands of creeping rivergrass until the population of the field, neighboring fields and irrigation waterways are completely controlled.

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