WATER-SEEDED RICE RESPONSE TO CLOMAZONE

A Thesis

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ABSTRACT

A study was conducted to evaluate rice cultivar tolerance to clomazone impregnated onto urea fertilizer and applied at the rice pegging (PEG) stage. A second study was conducted to evaluate rice injury, rice yield, and weed control with clomazone applied alone or in combination with bensulfuron or halosulfuron impregnated onto urea fertilizer applied at the PEG stage. Comparison treatments for weed control were also included in the study. In addition, a study was conducted to evaluate the safening potential of bensulfuron or halosulfuron applied with clomazone on rice grown hydroponically.

In the cultivar tolerance study, rice foliar bleaching was 16 to 20% at 14 d after PEG (DAPEG) for long-grain Ahrent, Cheniere, Cocodrie, Cypress, Francis, and Wells when clomazone was impregnated onto urea, and 23 and 30% for medium-grain Bengal and short-grain Pirogue, respectively. Clomazone reduced the number of tillers/m^2 21 DAPEG for all cultivars. Early season height reductions occurred for all cultivars; however, Pirogue was the only cultivar shorter than the nontreated at harvest. There were no yield reductions with regard to the medium and long-grain cultivars when compared with respective nontreated cultivars.

Rice foliar bleaching decreased from 42% with a single application of clomazone to 23 to 30% at 7 DAPEG when bensulfuron or halosulfuron were impregnated with clomazone. Barnyardgrass and broadleaf signalgrass control did not decrease with the addition of bensulfuron or halosulfuron to clomazone. A single application of clomazone controlled rice flatsedge 0% at 28 DAPEG; however, rice flatsedge control was greater than 76% for all bensulfuron and halosulfuron treatments at 28 DAPEG. There were no differences in rice yield between any herbicide treatments.

Bensulfuron and halosulfuron applied in a hydroponic solution, safened Bengal, Cocodrie, and Pirogue at 21 d after treatment from foliar bleaching

caused by clomazone. Chlorophyll content of all three rice cultivars decreased regardless of clomazone treatment. Only chlorophyll content of Cocodrie was increased by the addition of bensulfuron and halosulfuron compared with a single application of clomazone.

CHAPTER 1

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important crops produced in Louisiana with regard to both total acreage grown and its economic value (Sanders 2001). Although the United States grows only 1.3 million ha of rice, it exports more than 40% and currently ranks as the world's fourth largest exporter of rice (Childs and Burdett 2000). In the United States, rice is produced in two major regions; the Mississippi valley in the states of Arkansas (48% of total rice area), Louisiana (16%), Mississippi (8%), Missouri (6%), and Texas (6%), and the other is in north central California (15%) (Gealy et al. 2003; NASS 2004). For many decades, rice has been among the top cash crops produced in Louisiana. Rice production supports an infrastructure of storage, processing, transportation, and agricultural supply industries (Johnson et al. 1999). Production has expanded from the traditional rice-producing area of southwestern Louisiana to other areas of Louisiana, especially in northeastern Louisiana (Sanders 2001). A total of 215,400 hectares of rice was planted in Louisiana in 2002[1].

Water-seeding, a method of direct broadcasting dry or presoaked seed into flooded fields, is the predominant method of rice seeding used in Louisiana (Linscombe et al. 1999; Seaman 1983). In a water-seeded system, seed rice is submerged in water for approximately 24 h and allowed to drain for 12 h to initiate the germination process (Masson and Webster 2001). The pregerminated seeds are then broadcasted aerially into an established flood. Approximately 24 h after seeding, the field is drained to allow for seedling establishment.

Rice has been grown in flooded conditions for many years to aid in weed control (Adair and Engler 1955; Smith 1988b). Water seeding is an important

[1] Saichuk, J. K. 2002. Personal Communication.

cultural component of integrated weed management systems for rice (Smith 1988b). Weed control programs for water-seeded rice are more limited, and the risks of injury to the crop from herbicide treatments are higher when compared with dry-seeded rice (Seaman 1983). A higher level of soil moisture may increase the availability of herbicides to emerging shoots, resulting in increased absorption and the possibility of injury (Ketchersid et al. 1981; Knake et al. 1967). As the soil water content increases, herbicides with soil activity desorb and become available for plant uptake. With decreasing soil moisture, the herbicides tend to become adsorbed and less available for plant uptake (Beyer et al. 1988; Wehtje et al. 1987).

A complex of grass and broadleaf weeds exist in the water seeded rice culture of South Louisiana (Braverman 1995). The most common weeds include barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], broadleaf signalgrasss [*Brachiaria platyphylla* (Griseb.) Nash], ducksalad [*Heteranthera limosa* (Sw.) Willd.], hemp sesbania [*Sesbania exaltata* (Raf.) Rydb. Ex A. W. Hill], red rice (*Oryza sativa* L.), alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.], spreading dayflower (*Commelina diffusa* L.), Indian jointvetch (*Aeschynomene indica* L.), various sprangletops (*Leptochloa* spp.) and sedges (*Cyperus* spp.) (Chandler 1981; Jordan and Sanders 1999; Smith et al. 1977; Webster 2000). Controlling weeds in any crop is important (Smith 1988a). Weeds can reduce crop yield through competition, interference, and reduced crop quality and harvest efficiency (Czapar et al. 1997; Smith et al. 1977). Weeds compete with rice for light, nutrients, water, and other growth requirements (Smith et al. 1977). Rice yield reduction can be 80 to 100% under severe weed pressure (Smith 1988a).

Clomazone {2-[(2-chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidinone} was developed in the early 1980's and commercialized in 1985 (Ahrens 1994).

Clomazone[2] is a selective, preemergence herbicide used for control of annual grasses and some broadleaf weeds in cotton (*Gossypium hirsutum* L.), soybean [*Glycine max* (L.) Merr.], and other crops. This herbicide reduces or stops the accumulation of plastidic pigments in susceptible species, resulting in either white, yellow, or light green plants (Duke and Kenyon 1986). Some of the most troublesome grass weeds found in Louisiana rice are controlled by clomazone (Webster 2000). Most of the early research evaluating clomazone for use in rice was conducted with an emulsifiable concentrate (EC) formulation (Jordan et al 1998a; Johnson et al. 1995). In the mid 1990's, the formulation was changed to a microencapsulated (ME) formulation (Stringer et al. 1996). Clomazone was granted an emergency use exemption[3] in 1999 for use in drill-seeded rice production. In 2001, several Louisiana rice producing parishes received a supplemental label for clomazone to be used in water-seeded rice (Mudge et al. 2003). In order to be applied in water-seeded rice, clomazone must be impregnated onto fertilizer and the impregnated fertilizer is applied at a minimum of 168 kg/ha from 14 days prior to planting or during rice pegging up to reflooding but prior to weed emergence. Water must be removed completely from the field when making the application at the pegging stage.

Despite the residual activity of thiobencarb {S-[(4-chlorophenyl) methyl]diethyl-carbamothioate}, pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzeneamine], and quinclorac (3,7-dichloro-8-quinolinecarboxylic acid), these herbicides do not control grasses for the entire season (Baldwin 1995; Crawford and Jordan 1995; Jordan et al. 1998b). Clomazone controlled propanil-susceptible and –resistant barnyardgrass,

[2] Clomazone herbicide label. FMC Corporation, 1735 Market Street, Philadelphia, PA 19103.

[3] Clomazone 24(c) Exemption herbicide label. FMC Corporation, 1735 Market Street, Philadelphia, PA 19103.

sprangletop species, broadleaf signalgrass, and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] 30 days after rice planting (Mitchell and Gage 1999). Suppression of broadleaf weeds including Indian jointvetch, Pennsylvania smartweed (*Polygonum penslyvanicum* L.), pitted morningglory (*Ipomoea lacunosa* L.), and northern jointvetch (*Aeschynomene virginica* L.) were observed. Clomazone activity is influenced by factors such as soil moisture, soil type, and organic matter (Jordan et al. 1998a; Loux and Slife 1989; Mitchell and Hatfield 1996).

The influence of soil texture on clomazone activity appears to be largely linked to soil adsorption reactions, with clomazone having a strong affinity for clay and organic surfaces (Loux et al. 1989; Mervosh et al 1995). Clomazone applied to a silt loam soil resulted in greater rice foliar bleaching compared with a silty clay soil (Jordan 1998a). Mitchell and Hatfield (1996) also observed greater rice injury with the microencapsulated formulation (ME) of clomazone on a silt loam soil compared with a clay soil.

In greenhouse studies, Vencill et al. (1989) evaluated the effects of clomazone at 0.3, 0.6, and 1.1 kg ai/ha on a normal hybrid corn and a chlorophyll- and carotenoid-deficient albino mutant of corn. Visual observations of normal corn seedlings treated with clomazone revealed strong bleaching and retardation effects caused by all rates. Clomazone at 0.6 and 1.1 kg/ha reduced total chlorophyll content of normal corn. Total chlorophyll of the nontreated normal corn was 24.9 mg/g in comparison to 5.1 and 0.4 mg/g for 0.6 and 1.1 kg/ha, respectively.

Herbicide safeners, as suggested by their name, are ideally intended to limit the susceptibility of crop plants to herbicides without safening weed control (Devine et al. 1993). The herbicide, when applied alone, would either not be sufficiently active on the weeds at lower dose levels, or would cause some crop injury at the higher dose levels required for satisfactory weed control. It has been demonstrated that herbicides may interact before or after entering the plants and the outcome of the interaction can be synergistic, antagonistic, or additive depending on whether the combined effect on the plants is greater, less than or equal to the summed effect of the herbicides applied alone (Colby 1967; Green 1989; Hatzios and Penner 1985.) Antagonism defines a type of herbicide interaction, not whether a mixture is agronomically useful (Green 1989). Antagonism can often be managed and even be desired when it reduces crop injury.

Cotton in the later growth stages was found to tolerate POST-directed or layby applications of clomazone (Applewhite et al. 1988). Excessive injury occurred if clomazone was applied at the time of cotton planting (Applewhite et al. 1989; York et al. 1991). Organophosphate insecticides in combination with clomazone were evaluated on cotton as potential safeners for clomazone (Culpepper et al 2001; York et al. 1991). York et al. (1991) reported in-furrow applications of disulfoton {O,O-Diethyl S-[2-(ethylthio)ethyl] phosphorothithiote} or phorate {O,O-diethyl S[(ethylthio)methyl] phosphorodithioate} greatly reduced clomazone-induced chlorosis, stunting, and death of cotton seedlings.

Studies were also conducted to determine if seed treated with disulfoton could reduce bleaching of rice foliage caused by clomazone (Jordan et al. 1998a). Clomazone at 0.56, 1.1, 1.7, and 2.2 kg/ha was applied delayed preemergence (DPRE) to 'Cypress' rice treated with disulfoton at 0, 3, 6, and 12 g ai/kg of seed. Rice bleaching from clomazone at 1.7 kg/ha without a seed treatment was 29 and 59% on silty clay and silt loam soil, respectively; however, the addition of disulfoton at 12 g/kg of seed reduced bleaching to 6 and 16% on both soil types, respectively.

A practice commonly used today is the application of two or more herbicides sequentially or in combination to broaden the spectrum of weed control, reduce production cost, and/or prevent the development of weeds resistant to certain herbicides (Bruff and Shaw 1992; Kelly and Coats 1999;

Zhang et al. 1995). When multiple weed problems exist, it becomes advantageous to use a mixture of herbicides to control both broadleaf and grass weeds (Brommer et al 2000).

In rice, multiple application costs are incurred because most aerial applicators cannot apply granular and aqueous sprays simultaneously (Braverman 1995). Applying herbicides coated onto or impregnated onto granular fertilizers decreases costs by eliminating an application compared with multiple applications (Kelly and Coats 1999). Simultaneous applications of herbicides with fertilizer save time and labor and reduce soil compaction by eliminating field operations (Buhler 1987). Due to their physical nature, granular herbicide formulations are less likely to drift (Zimdahl 1993). Applications of herbicides at labeled rates on dry fertilizers are widely used and appear to be consistently and predictably effective (Rabaey and Harvey 1993). Baker et al. (1990) reported increased weed control in water-seeded rice with fertilizer granules impregnated with bensulfuron {2-[[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]methyl] benzoic acid}. Triasulfuron {2-(2-chloroethoxy)-N-[[(4-methoxy-6-methyl-1,3,5-5-triazin-2-yl)amino]carbonyl] benzenesulfonamide} and chlorsulfuron {2-chloro-N-[[(4-methoxy-6-methyl-1,3,5-5-triazin-2-yl)amino]-carbonyl] benzenesulfonamide}, both sulfonylurea herbicides, were impregnated onto diammonium phosphate granular fertilizer incorporated prior to planting and after winter wheat (*Triticum aestivum* L.) emergence (Koscelny and Peeper 1996). These treatments were compared with broadcast sprays applied postemergence (POST) with water as the carrier. Granular fertilizer applied PPI was a successful carrier for sulfonylurea herbicides for henbit (*Lamium amplexicaule* L.) and bushy wallflower (*Erysimum repandum* L.) control in winter wheat.

Sulfonylureas are a highly active class of herbicides with low application rates (Gomez et al. 1993). Bensulfuron-methyl and halosulfuron-methyl {3-chloro-5-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino] sulfonyl]-1-methyl-1H-pyrazole-4-carboxylic acid} are sulfonylurea herbicides registered for use as POST treatments to control sedges in rice (Carpenter et al. 1999; Hill et al. 1990; Jordan 1995). Braverman (1995) evaluated weed control in water-seeded rice with granular molinate (S-ethyl hexahydro-1H-azepine-1-carbothioate) or fertilizer granules coated with bensulfuron. Fertilizer coated with bensulfuron at 111 g ai/ha controlled ducksalad 86 to 96%. At 19 to 32 g/ha bensulfuron controlled alligatorweed, ducksalad, smartweed, hemp sesbania, and redstem (*Ammannia auriculata* Willd.) in water seeded rice (Bozarth et al. 1988). Control of ducksalad with bensulfuron of was more reliable with the fertilizer carrier than granular molinate as the carrier. However, bensulfuron has little to no activity on barnyardgrass and bensulfuron impregnated on fertilizer had little practical use in water-seeded rice (Brommer et al. 2000; Jordan 1995).

In comparison with a drill-seeded rice production system, water-seeded rice is typically injured more by clomazone (Jordan et al. 1998a). The supplemental clomazone label allows the herbicide to be impregnated onto fertilizer and applied at the rice pegging stage (PEG). Webster et al. (2002) evaluated the possibility of broadening weed control spectrum by impregnating bensulfuron or halosulfuron plus clomazone onto urea and applying at the PEG stage. The mixture treatments not only controlled sedges, but also decreased early season rice injury caused by clomazone.

The overall objective of this research was to evaluate herbicide/fertilizer combinations applied to pegging rice in a water-seeded production system. The first objective was to evaluate clomazone tolerance of eight long, medium, and short-grain rice cultivars in a water-seeded rice production system. The second objective was to evaluate potential safening effects and weed control of bensulfuron or halosulfuron impregnated at various rates with the labeled rate of clomazone onto urea. A laboratory study was also conducted to evaluate the effects of herbicide combinations on chlorophyll content of long, medium, and short grain rice to determine if differential response among grain types could be determined.

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CHAPTER 2

RICE (*ORYZA SATIVA* L.) CULTIVAR TOLERANCE TO CLOMAZONE IN WATER-SEEDED PRODUCTION

Introduction

Differential crop response to herbicides can be displayed in a number of ways including injury symptoms, reduction in growth, and yield (Wixson and Shaw 1991). Several crops, including soybean [*Glycine max* (L.) Merr.], potato (*Solanum tuberosum* L.), corn (*Zea mays* L.), and wheat (*Triticum aestivum* L.) have displayed differences in cultivar tolerance to herbicides (Edwards et al. 1976; Graf and Ogg 1976; Newsom and Shaw 1992; Renner et al. 1988; Runyan et al. 1982). Griffin and Baker (1990) evaluated 'Mars', a medium grain rice cultivar, and 'Lemont' and 'Tebonnet', both long-grain cultivars, for tolerance to fenoxaprop {2-[4-[(6-chloro-2-benzoxazolyl)oxy] phenoxy] propanoic acid}, sethoxydim {2-[1-ethoxyimono)butyy]-5-[2-(ethylthio) propyl-3-hydroxy-2-cyclohexen-1-one}, and haloxyfop {2-[4-[[3-chloro-5-trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid}. Rice plant height and stand loss increased with applications made after permanent flood establishment compared with an application prior to permanent flood with all cultivars and all herbicides evaluated. Yield of Mars was reduced from 11 to 23% by fenoxaprop at both application timings, respectively. Applications of fenoxaprop after flood establishment reduced Lemont and Tebonnet yields.

Clomazone {2-[(2-chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidinone} has been evaluated in both drill and water seeded rice (Jordan et al. 1998; Scherder et al. 1999; Webster et al. 1999). Although rice has shown acceptable tolerance to clomazone, substantial injury can occur under certain conditions (Mitchell and Hatfield 1996). Clomazone received registration for use in weed control in southern dry-seeded rice in 1999 (Mitchell and Gage 1999; Scherder et al. 2000). Webster et al. (1999) reported that clomazone applied preemergence (PRE) injured rice 8 to 12% at 7 d after emergence at 0.45, 0.56, and 0.67 kg ai/ha. Although, injury may be significant after a soil application, Webster indicates rice has the ability to overcome early-season foliar bleaching, by 14 to 28 d after treatment (DAT). Jordan et al. (1998) observed up to 35% injury at 14 DAT when 'Cypress' was drill-seeded and treated with the emulsifiable concentrate (EC) formulation of clomazone at 0.56 kg/ha. Increasing clomazone rate to 1.7 to 2.2 kg/ha delayed days to 50% seed head emergence and reduced grain yield. When microencapsulated (ME) clomazone was applied at 0.28 or 0.56 kg/ha, rice foliar bleaching was 15% or less with no maturity delay or yield reduction observed (Bollich et al. 2000). Talbert et al. (1999) reported 3, 18, and 60% rice foliage bleaching at 7 DAT when clomazone was applied at 0.45 kg/ha PRE, delayed PRE (DPRE), and preplant incorporated (PPI), respectively. Rice foliar bleaching was less than 5% by 28 DAT. Webster et al. (2002) applied clomazone at different timings and rates in water-seeded rice. Injury was 6% or less 14 DAT when applied PPI or PRE; however, injury increased up to 26% when clomazone was impregnated on a fertilizer granule and applied at rice pegging (PEG).

Talbert et al. (1999) evaluated ten rice cultivars for sensitivity to clomazone. Clomazone at 0.22 and 0.45 kg/ha was applied DPRE to 'Alan', 'Bengal', Cypress, 'Drew', 'Kaybonnet', 'Koshihikari', 'Lagrue', Lemont, Mars, and 'Priscilla'. Clomazone rate did not affect the degree of chlorosis observed at 7 and 14 DAT. However, Mars, Alan, and Kaybonnet were more tolerant to clomazone than Bengal, Drew, Koshihikari, Lemont, and Priscilla. In a drill-seeded production system ten rice cultivars in Louisiana were evaluated for crop response when treated with clomazone at 1.12 kg/ha PRE (Webster et al. 2002). Rice injury was 49 to 78% at 16 d after PRE (DAPRE) for all cultivars, and reductions in plant height were observed with the treated compared with the nontreated within each cultivar for Cypress, ‘Wells’, and ‘Earl’. However, early season injury and height reduction did not translate into a yield reduction for any cultivar.

Zhang et al. (2004) evaluated the tolerance of nine rice cultivars to clomazone in a drill-seeded rice production system. Clomazone was applied preemergence (PRE) at 0 and 1.12 kg/ha to the medium-grain cultivars Bengal, Earl, ‘LL-401’, and ‘LL-601’ and the long-grain cultivars ‘Cocodrie’, ‘CL-141’, Cypress, Drew, and Wells. Rice bleaching was 43 to 51% and 27 to 43% at 14 DAT for all medium- and long-grain rice cultivars, respectively. Long-grain Drew was injured less than all the medium-grain cultivars. Rice grain yield of LL-401 was reduced when treated with clomazone. Despite early season rice injury with clomazone, most cultivars were able to recover from the initial injury and maintain grain yield potential.

Scherder et al. (2000) applied clomazone at 0.34 and 0.67 kg/ha PRE to medium and long-grain rice cultivars. Mars, Lemont, Kaybonnet, and Cypress were found to be tolerant to clomazone, and Bengal, Cocodrie, Drew, and Wells displayed moderate tolerance. Previous research indicated that tolerance of rice cultivars to V-10029 (Zhang and Webster 2002) and clomazone (Zhang et al. 2004) could be more easily differentiated when the use rate was two times the labeled rate. Research to this point has evaluated rice response to clomazone applied in aqueous solution and in most cases in a drill-seeded production system. The objective of this study was to evaluate the tolerance of selected rice cultivars to clomazone impregnated at a rate of 896 g/ha onto urea applied at 168 kg/ha to rice in the PEG stage in a water-seeded culture.

Materials and Methods

A study was conducted at the LSU AgCenter Rice Research Station near Crowley, La in 2002 and 2003. Soil was a Crowley silt loam (fine montmorillinitic, thermic Typic Albaqualf), with 6.4 pH and 1.4% organic matter. Seedbed preparation consisted of a fall and spring disking followed by (fb) two passes in opposite directions using a two-way bed conditioner with rolling baskets and S-tine harrows set at a depth of 6 cm. The study area was laser-leveled in the winter to a slope gradient of 0.25% following initial disking. A 5-cm flood was established prior to rice planting. Plot size was 1.5 m wide by 5.2 m long.

Rice seeds were submerged in a water-filled container for 24 h, removed, and allowed to drain for 12 h to initiate the germination process. Pregerminated seeds were broadcast by hand into a 5-cm standing flood at a seeding rate of 168 kg/ha on April 25, 2002 and April 16, 2003, respectively. After 24 h, the field was drained to allow for seedling establishment.

The experimental design was a randomized complete block with a two factor factorial arrangement of treatments with four replications. Factor A consisted of six long-grain rice cultivars 'Ahrent', 'Cheniere', Cocodrie, Cypress, 'Francis', and Wells, one medium-grain cultivar Bengal, and one short grain cultivar 'Pirogue'. Factor B consisted of microencapsulated (ME) clomazone[4] applied at 0 and 896 g/ha. Clomazone was impregnated onto 46-0-0 (N-P-K) urea nitrogen. The herbicide coated with fertilizer was mixed for 5 minutes in an Imer Minuteman Portable Electric 0.14 m^3 Concrete Cement Mixer[5] to ensure adequate coating of the herbicide onto the urea fertilizer. A 118 ml sample of clomazone was coated onto 7968 g of urea fertilizer using the cement mixer. A 133 g sample of the herbicide-coated fertilizer was broadcast by hand at 168 kg/ha at the PEG stage of rice on May 1, 2002 and April 28, 2003. The PEG stage refers to the growth of the rice at which the primary root penetrates the soil surface, usually occurring 4 to 7 d after planting. The nontreated of each variety received 168 kg/ha non-impregnated urea.

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[4] Clomazone herbicide label. FMC Corporation, 1735 Market Street, Philadelphia, PA 19103.

[5] Imer USA, Inc. 207 Lawrence Avenue, South San Francisco, CA 94080.

Permanent flood was established 24 hrs after clomazone PEG treatments were applied and was maintained until 2 weeks prior to harvest. Soil fertility management consisted of 280 kg/ha of 7-21-21 (N-P-K) fertilizer preplant and 280 kg/ha of 46-0-0 (N-P-K) urea nitrogen immediately before permanent flood. Standard agronomic and pest management practices were employed during the growing season to maximize yield (Linscombe et al. 1999).

A package mixture[6] of 1.68 kg ai/ha propanil [N-(3,4-dichlorophenyl) propanamide] plus 1.68 kg ai/ha molinate (S-ethyl hexahydro-1H-azepine-1-carbothioate) and halosulfuron {3-chloro-5-[[[[(4,6-dimethoxy-2-pyrimidinyl) amino]carbonyl]amino]sulfonyl]-1-methyl-1H-pyrazole-4-carboxylic acid} at 42 g ai/ha, in 2002 and cyhalofop {(R)-2-[4-(4-cyano-2-fluorophenoxy)phenoxy] propanoic acid} at 313 g ai/ha and halosulfuron at 42 g/ha in 2003, were applied before permanent flood establishment when rice was at the four- to five-leaf stage, to maintain rice weed-free and insure harvestibility. All POST herbicide applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L/ha spray volume at 168 kPa.

Visual estimates of rice injury were expressed as rice foliar bleaching and were determined 7, 14, 28, and 56 d after PEG (DAPEG) on a scale of 0 to 100%, where 0 = no chlorosis/bleaching and 100 = total rice foliar chlorosis or bleaching. Visual bleaching ratings were based on the nontreated control of each cultivar. Plant height was recorded from the soil surface to the tip of the longest leaf or the extended panicle at maturity. The average height of two plants per plot was considered as the height of the experimental unit. Rice stand was recorded 14 and 21 DAPEG by counting the number of tillers in a randomly selected area of 0.065 m^2. Final rice stand was converted to tillers/m^2. Rice grain was machine harvested on August 22, 2002 and August

[6] Arrosolo herbicide label. RICECO Corporation, 5100 Popular Avenue, Suite 2428, Memphis, TN 38173.

18, 2003 with a small-plot combine. Final rice yield was adjusted to 12% moisture.

Final data for rice bleaching, rice stand, rice height, and rough rice grain yield were subjected to the Mixed Procedure of SAS (SAS Institute 1999) with year used as a random factor. Years, replication (nested years), and all interactions containing either of these effects were considered random effects; treatment was considered a fixed effect. Considering year or combination of year and location as environments or random effects permits inferences about treatments to be made over a range of environments (Carmer et al. 1989; Hager et al. 2003). Type III statistics were used to test all possible effects of fixed factors (rice cultivar, clomazone treatment, and rice cultivar by clomazone treatment). Least square means were used for mean separation at $p \leq 0.05$.

Results and Discussion

Since cultivar by clomazone treatment interaction occurred for rice bleaching at 7, 14, and 28 DAPEG, population at 14 and 21 DAPEG, plant height at 14 DAPEG and harvest, and rice grain yield, tables were established to reflect these interactions.

At 7 DAPEG, clomazone injured short-grain Pirogue 30% which was greater than bleaching of Ahrent, Cheniere, Cocodrie, Cypress, Francis, Wells, and Bengal (Table 2.1). Medium-grain Bengal injury was 24%, which was greater than Cheniere, Cocodrie, Cypress, and Wells. No bleaching differences were noted between the long-grain rice cultivars Ahrent, Cheniere, Cocodrie, Cypress, Francis, and Wells. Scherder et al. (2000) reported chlorosis and rice injury to long and medium-grain cultivars to be less than 15% at 7 d after emergence (DAE) in a drill-seeded production system.

At 14 DAPEG, rice bleaching was similar to bleaching 7 DAPEG with all cultivars evaluated (Table 2.2). Bengal and Pirogue foliage was bleached 23 and 30%, respectively, which were greater than bleaching for any other

Table 2.1. Rice cultivar foliar bleaching at 7 d after pegging treatment of clomazone impregnated onto 168 kg/ha of 46-0-0 (N-P-K) urea nitrogen fertilizer and p-values to compare bleaching differences between cultivars.[a-c]

Cultivar	Grain type	Cultivar							Bleaching
		Cheniere	Cocodrie	Cypress	Francis	Wells	Bengal	Pirogue	
		p > |t|							%
Ahrent	Long	0.2812	0.6657	0.6657	0.2812	0.6657	0.0107	<0.0001	20 c
Cheniere	Long		0.5171	0.5171	0.0325	0.5171	0.0004	<0.0001	19 c
Cocodrie	Long			1.0000	0.1324	1.0000	0.0031	<0.0001	19 c
Cypress	Long				0.1324	1.0000	0.0031	<0.0001	19 c
Francis	Long					0.1324	0.1324	<0.0001	22 bc
Wells	Long						0.0031	<0.0001	19 c
Bengal	Medium							<0.0001	24 b
Pirogue	Short								30 a

[a] Clomazone applied at 896 g/ha.
[b] Compare bleaching means using the p-values in the table.
[c] Means followed the same lowercase letter were not significant according to the t-test on difference of least square means at $P \leq 0.05$.

Table 2.2. Rice cultivar foliar bleaching at 14 d after pegging treatment of clomazone impregnated onto 168 kg/ha of 46-0-0 (N-P-K) urea nitrogen fertilizer and p-values to compare bleaching differences between cultivars.[a-c]

Cultivar	Grain type	Cultivar: Cheniere	Cocodrie	Cypress	Francis	Wells	Bengal	Pirogue	Bleaching
		p > |t|							%
Ahrent	Long	<0.0001	0.2319	0.5490	0.0742	0.0005	0.0179	<0.0001	20 c
Cheniere	Long		0.0005	<0.0001	0.0033	0.2319	<0.0001	<0.0001	16 e
Cocodrie	Long			0.5490	0.5490	0.0179	0.0005	<0.0001	19 cd
Cypress	Long				0.2319	0.0033	0.0033	<0.0001	20 c
Francis	Long					0.0742	<0.0001	<0.0001	19 cd
Wells	Long						<0.0001	<0.0001	17 de
Bengal	Medium							<0.0001	23 b
Pirogue	Short								30 a

[a] Clomazone applied at 896 g/ha.
[b] Compare bleaching means using the p-values in the table.
[c] Means followed the same lowercase letter were not significant according to the t-test on difference of least square means at $P \leq 0.05$.

cultivars. In a drill-seeded rice study, Bengal was injured 43% when clomazone was applied at a higher rate of 1.12 kg/ha at 14 DAT (Zhang et al. 2004). At 14 DAPEG, Cheniere was bleached 16%, which was less than any other cultivar, except Wells. This is different from research reported by Scherder et al. (2000), which found Wells to be moderately tolerant when treated with clomazone at 0.67 kg/ha.

Cheniere was bleached 10%, compared with Pirogue with 20% bleaching at 28 DAPEG (Table 2.3). There were no differences in bleaching between all other cultivars at this rating date. By 56 DAPEG foliar bleaching was less than 10% for all cultivars evaluated (data not shown). Scherder et al. (2000) reported differences in cultivar chlorosis and injury when rice was drill-seeded at 28 d after emergence when treated with clomazone at 0.67 kg/ha applied PRE; however, no differences were observed at subsequent evaluations. Based on the bleaching data, the long-grain cultivars appear to be more tolerant to clomazone than medium-grain Bengal or short-grain Pirogue.

Plant population comparisons were made within a cultivar for the treated and nontreated at 14 DAPEG (Table 2.4). There were less tillers/m^2 for the clomazone treated Ahrent, Cheniere, Cypress, Francis, and Pirogue when compared with the respective nontreated. At 21 DAPEG, rice plant population of all cultivars treated with clomazone was less than their respective nontreated (Table 2.5). Rice cultivars treated with clomazone were reduced in total tiller production by 150 to 310 tillers/m^2. Rice cultivars treated with clomazone resulted in shorter plants for Cypress, Francis, Wells, and Bengal compared with respective nontreated at 14 DAPEG (Table 2.6). Growth inhibition, as reflected by plant height, was probably

Table 2.3. Rice cultivar foliar bleaching at 28 d after pegging treatment of clomazone impregnated onto 168 kg/ha of 46-0-0 (N-P-K) urea nitrogen fertilizer and p-values to compare bleaching differences between cultivars.[a-c]

	Grain	Cultivar							
Cultivar	type	Cheniere	Cocodrie	Cypress	Francis	Wells	Bengal	Pirogue	Bleaching
		p > |t|							%
Ahrent	Long	0.5686	0.9189	0.8545	0.7445	0.7291	0.2638	0.0121	12 ab
Cheniere	Long		0.6395	0.6987	0.3709	0.3601	0.0930	0.0023	10 b
Cocodrie	Long			0.9350	0.6688	0.6541	0.2231	0.0092	12 ab
Cypress	Long				0.6107	0.5965	0.1940	0.0073	12 ab
Francis	Long					0.9837	0.4275	0.0281	13 ab
Wells	Long						0.4394	0.0296	13 ab
Bengal	Medium							0.1557	16 ab
Pirogue	Short								20 a

[a] Clomazone applied at 896 g/ha.
[b] Compare bleaching means using the p-values in the table.
[c] Means followed the same lowercase letter were not significant according to the t-test on difference of least square means at $P \leq 0.05$.

Table 2.4. Rice populations at 14 d after pegging treatment of clomazone impregnated onto 168 kg/ha of 46-0-0 (N-P-K) urea nitrogen fertilizer and p-values to compare population differences between the treated and the nontreated within a rice cultivar.[a,b]

Cultivar	Grain type	Plant population Treated	Nontreated	Difference	P-value
		——— tillers/m^2 ———			p > |t|
Ahrent	Long	370	580	-210	0.0006
Cheniere	Long	320	520	-200	0.0008
Cocodrie	Long	420	500	-80	0.1652
Cypress	Long	310	440	-130	0.0262
Francis	Long	300	470	-170	0.0047
Wells	Long	400	500	-100	0.0892
Bengal	Medium	210	310	-100	0.1082
Pirogue	Short	180	370	-190	0.0013

[a] Clomazone applied at 896 g/ha.
[b] Compare population differences between the treated and the nontreated within a cultivar using the p-values.

Table 2.5. Rice populations at 21 d after pegging treatment of clomazone impregnated on 168 kg/ha of 46-0-0 (N-P-K) urea nitrogen fertilizer and p-values to compare population differences between the treated and the nontreated within a rice cultivar.[a,b]

Cultivar	Grain type	Plant population: Treated	Plant population: Nontreated	Plant population: Difference	P-value
		——— tillers/m^2 ———			p > |t|
Ahrent	Long	290	600	-310	<0.0001
Cheniere	Long	390	670	-280	<0.0001
Cocodrie	Long	380	530	-150	0.0098
Cypress	Long	340	540	-200	0.0006
Francis	Long	370	530	-160	0.0042
Wells	Long	380	560	-180	0.0035
Bengal	Medium	190	380	-190	0.0014
Pirogue	Short	160	470	-310	<0.0001

[a] Clomazone applied at 896 g/ha.
[b] Compare population differences between the treated and the nontreated within a cultivar using the p-values.

Table 2.6. Rice height 14 d after pegging treatment of clomazone impregnated on 168 kg/ha of 46-0-0 (N-P-K) urea nitrogen fertilizer and p-values to compare height differences between the treated and the nontreated within a rice cultivar.[a,b]

Cultivar	Grain type	Plant height Treated	Nontreated	Difference	P-value
		——— cm ———			P > |t|
Ahrent	Long	23	23	0	0.9057
Cheniere	Long	22	23	-1	0.4077
Cocodrie	Long	23	24	-1	0.1257
Cypress	Long	21	23	-2	0.0261
Francis	Long	23	26	-3	0.0008
Wells	Long	26	28	-2	0.0461
Bengal	Medium	23	30	-7	<0.0001
Pirogue	Short	20	22	-2	0.1257

[a] Clomazone applied at 896 g/ha.
[b] Compare height differences between the treated and the nontreated within a cultivar using the p-values.

caused by the interference of clomazone with chloroplast development and carotenoid and chlorophyll synthesis as indicated by Duke et al. (1985).

Early season height reductions from the clomazone treated cultivars were not observed at harvest, except with Pirogue (Table 2.7). The treated long-grain cultivars, Cocodrie and Cypress were taller than the respective nontreated. Zhang et a. (2004), reported that clomazone at 1.12 kg/ha reduced rice plant height and population early in the growing season.

There were no yield reductions with regard to the medium and long-grain cultivars when compared within the nontreated cultivar (Table 2.8). Rice yield of Pirogue treated with clomazone was 1740 kg/ha less than the nontreated. In a cultivar tolerance study, Patone and Baker (1992) found a correlation between percent injury with grain yield reduction revealing that visual ratings were relatively good predictors of grain yield for triclopyr {[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid}. The relationship between injury ratings and yield reductions was highly significant for triclopyr for rice cultivars Lemont, Mars, and Tebonnet. Although a herbicide may injure a crop, yields may increase due to weed control as compared with a weedy crop (Baker et al. 1988). By removing the confounding factor of weeds, the actual herbicide injury to the crop can be determined.

In conclusion, these data indicate clomazone causes rice injury and reduces stand and height of the long, medium, and short grain cultivars evaluated in this study. Foliar bleaching was 19 to 22% for all long-grain cultivars at 7 DAPEG. By 56 DAPEG, foliar bleaching was less than 10% for all cultivars. These results differ from a drill-seeded planting system study in which bleaching was less than 8% by 14 DAT for the majority of the long and medium-grain cultivars evaluated (Scherder et al. 2000). Cheniere is a relatively new long-grain rice cultivar released by the LSU AgCenter. This cultivar was bleached less than the other cultivars evaluated except for Wells, a release from the University of Arkansas. All other long-grains

Table 2.7. Rice height at harvest of plants treated with clomazone impregnated onto 168 kg/ha of 46-0-0 (N-P-K) urea nitrogen fertilizer and p-values to compare height differences between the treated and the nontreated within a rice cultivar.[a,b]

Cultivar	Grain type	Plant height: Treated	Plant height: Nontreated	Plant height: Difference	P-value
		cm	cm	cm	p > |t|
Ahrent	Long	108	107	+1	0.6314
Cheniere	Long	97	96	+1	0.6314
Cocodrie	Long	102	97	+5	0.0348
Cypress	Long	102	96	+6	0.0101
Francis	Long	107	104	+3	0.1842
Wells	Long	110	108	+2	0.3120
Bengal	Medium	98	99	-1	0.5940
Pirogue	Short	101	106	-5	0.0250

[a] Clomazone applied at 896 g/ha.
[b] Compare height differences between the treated and the nontreated within a cultivar using the p-values.

Table 2.8. Rice grain yield of plants treated with clomazone impregnated on 168 kg/ha of 46-0-0 (N-P-K) urea nitrogen fertilizer and p-values to compare yield differences between the treated and the nontreated within a rice cultivar.[a-c]

	Grain	Grain yield			
Cultivar	type	Treated	Nontreated	Difference	P-value
		———	kg/ha	———	p > |t|
Ahrent	Long	7560	7460	+100	0.8430
Cheniere	Long	7670	7420	+250	0.6351
Cocodrie	Long	7290	7710	-420	0.4075
Cypress	Long	6340	5850	+490	0.3386
Francis	Long	7590	6940	+650	0.2111
Wells	Long	7540	7880	-340	0.5099
Bengal	Medium	6520	6210	+310	0.5413
Pirogue	Short	7000	8740	-1740	0.0010

[a] Clomazone applied at 896 g/ha.
[b] Rough rice yield adjusted to 12% moisture content.
[c] Compare rice yield differences between the treated and the nontreated within a cultivar using the p-values.

exhibited similar tolerance to clomazone. Previous research has indicated medium-grain rice cultivars are injured more by herbicides than long-grain cultivars (Zhang et al. 2002; Lanclos et al. 1999). In this study, Bengal was bleached more than all cultivars except the short-grain Pirogue. Rice stands cannot be relied on as indicators of yield. The number of tillers/m^2 was reduced for the clomazone treated plants. Despite early season foliar bleaching and stand reductions, yield of the clomazone treated cultivars was not reduced for the medium grain Bengal or any of the long-grains evaluated. Previous research has indicated clomazone at 0.56 kg/ha did not reduce grain yield of the long-grain Cypress (Bollich et al. 2000). Yield was reduced at 0.84 to 2.2 kg/ha in drill and water-seeded production when the soil was wet approximately 1 wk after seeding and clomazone application. Greater injury was noted in the short-grain Pirogue, which resulted in a yield reduction; therefore, these data suggest that clomazone should not be used with this cultivar. Short-grain rice cultivars are grown on limited hectarage in Louisiana.

The clomazone rate used in this study was 896 g/ha which is greater than the manufacturers suggested rate of 340 to 670 g/ha. Thus, a PEG application of clomazone within labeled application rates should be safe for most of the rice cultivars evaluated except Pirogue. Applying clomazone at lower rates will probably result in reduced foliar bleaching.

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CHAPTER 3

RICE (*ORYZA SATIVA* L.) RESPONSE TO CLOMAZONE PLUS BENSULFURON AND HALSOSULFURON

Introduction

The basis for clomazone {2-[(2-chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidinone} selectivity is not fully understood (Culpepper et al. 2001). Differential absorption, translocation, or metabolism does not adequately explain differences in selectivity among species (Liebl and Norman 1991; Scott and Weston 1992; Weimer et al. 1992; Weston and Barrett 1989). Susceptible seedlings usually emerge from the treated soil, but are bleached and become necrotic after several days (Ahrens 1994). This herbicide is readily absorbed by roots and is not highly absorbed when foliar applied.

Annual grasses continue to be prominent in rice production in the southern U.S. Jordan et al. (1998). A single barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] plant/m^2 can reduce rice yields 25% (Miller 1993). Previous research has demonstrated that barnyardgrass control clomazone equals or exceeds that with other residual herbicides registered for use in rice (Hatfield and Mitchell 1996; Jordan et al. 1996; Jordan et al. 1998; Kendig et al. 1996; Miller and Jordan 1997). Clomazone at 0.34 and 0.44 kg ai/ha controlled barnyardgrass 96 and 99%, respectively, when applied delayed preemergence (DPRE) (Williams and Burns 1999). Control of Amazon sprangletop [*Leptochloa panicoides* (Presl) Hitchc.] and broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash] were similar to barnyardgrass. Increased weed control has resulted in higher yields when clomazone was evaluated against other rice herbicides such as quinclorac (3,7-dichloro-8-quinolinecarboxylic acid), thiobencarb {S-[(4-chlorophenyl)methyl]diethyl-carbamothioate}, and pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzeneamine] (Mitchell and Gage 1999). Clomazone has excellent activity on most grass weeds in rice; but a program approach will be needed if broadleaf weed species are present (Scherder et al. 1999).

In drill-seed rice, bleaching of rice foliage 14 d after treatment (DAT) from clomazone applied alone at 1.7 kg/ha was 29 and 59% on silty clay and silt loam soils, respectively (Jordan et al. 1998a). Injury caused by clomazone increased the number of days from seedling emergence to 50% seed head emergence in five of eight experiments conducted in drill- and water-seeded rice, indicating a delay in maturity may occur (Bollich et al. 2000).

In initial research, clomazone applied pre-plant incorporated (PPI) or PRE caused excessive cotton injury (Applewhite et al. 1988). Subsequent experimentation demonstrated a reduction in injury to cotton when clomazone was applied in combination with the organophosphate insecticides phorate {O,O-diethyl S[(ethylthio)methyl]phosphorodithioate} and disulfoton {O,O-Diethyl S-[2-(ethylthio)ethyl]phosphorothithiote} (Applewhite and Mitchell 1990; York et al. 1991). Clomazone at 1.1 kg/ha applied PRE caused 46 to 51% cotton injury at 21 d after planting and reduced cotton stands 14 to 32% (York et al. 1991). In contrast, clomazone at 0.87 kg/ha in combination with disulfoton or phorate injured cotton less than 4% and did not reduce stands. Clomazone applied alone reduced root and shoot growth 26 to 33%, while root and shoot growth were not reduced with the two insecticides applied infurrow (Culpepper et al. 2001).

There has been considerable interest in the use of herbicide safeners to enhance crop tolerance to a number of herbicides (Seguin et al. 1999). The safening effect increases the margin of tolerance of the herbicide and allows for improved control of problem weeds with the herbicide-safener combination (Devine et al. 1993). Hoffman (1962) introduced the concept of increasing crop selectivity to herbicides by using a seed-applied safener (4’-chloro-2-hydroxyiminoacetanilide, 2,4-dichloro-9-xanthenone, and N-methyl-3,4-dichlorobenzene sulfonamide) to reduce barban (4-chloro-2-butynyl-3-chlorophenylcarbamate) injury to wheat (*Triticum aestivum* L.).

Protection of cotton from clomazone injury by disulfoton and phorate insecticides may be partially due to an effect on clomazone metabolism (Culpepper et al. 2001). Cotton plants treated with ^{14}C-clomazone plus disulfoton or phorate insecticides resulted in an increased percentage of ^{14}C in both roots and shoots compared with plants receiving clomazone alone. These results suggest that clomazone may not be the phytotoxic agent in cotton. Corn (*Zea mays* L.) seed treated with naphthalic anhydride (NA) (1H,3H-naphtho[1,8-cd]-pyran-1,3-dione) at 0.5% (w/w) was shown to significantly reduce crop injury from clomazone (Krausz and Kapusta 1992). At 10 days after planting (DAP), injury was 70 and 80% when clomazone was applied at 0.56 and 0.70 kg/ha, respectively, compared with 5 and 7% where NA treated seed were planted. Plant population, height, ear number, and grain yield were higher with NA treated corn seed.

Clomazone applied PRE at 0.45 to 0.67 g/ha suppresses key broadleaf weeds in rice such as northern jointvetch (*Aeschynomene virginica* L.), pitted morningglory (*Ipomoea lacunose* L.), and prickly sida (*Sida spinosa* L.) (Mitchell and Gage 1999); however, additional treatments are often required for control of other broadleaf weeds and sedges (Williams and Burns). Broadleaf weeds are a significant problem in cultivated rice (Brommer et al. 2000).

Acetolactate synthase (ALS) is the target enzyme for the sulfonylurea herbicide chemistry class (Ray 1984). Sulfonylurea herbicides contain desirable characteristics such as low mammalian toxicity, low usage rates, a high degree of selectivity, and good efficacy on difficult to control weed species (Carpenter et al. 1999). Bensulfuron {2-[[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino] sulfonyl]methyl]benzoic acid} and halosulfuron {3-chloro-5-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl] amino]sulfonyl]-1-methyl-1H-pyrazole-4-carboxylic acid} are postemergence (POST) sulfonylurea herbicides labeled for use in rice. Bensulfuron controls several broadleaf weeds in rice and consistently controls yellow nutsedge (*Cyperus esculentus* L.) (Jordan 1995). In California, bensulfuron at 0.07 kg ai/ha controlled both smallflower umbrella sedge (*Cyperus dissormis* L.) and ricefield bulrush (*Scirpus mucronatus* L.) 98 to 100% and 85 to 93%, respectively. Bensulfuron at 0.112 kg/ha impregnated onto fertilizer controlled yellow nutsedge 88% (Baker et al. 1990). A single application of halosulfuron at 70 g ai/ha controlled yellow nutsedge greater than 80% in bermudagrass [*Cynodon dactylon* (L.) Pers.] turf (Blum et al. 2000).

Rice fields are often infested with several grass and broadleaf weeds plus annual and perennial sedges (*Cyperus* spp.), and timing of POST herbicide applications for control of these weeds often coincide. Producers would prefer to apply herbicides in a mixture for convenience, to save time, and reduce application costs (Jordan 1995). Reduced grass control often results when graminicides are applied with herbicides active on broadleaf and sedge weeds (Ferriera and Coble 1994; Hahn and Coble 1989; Myers and Coble 1992). Bensulfuron at 52 g/ha did not reduce barnyardgrass control with fenoxaprop-ethyl {2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid} applied at 56, 75, or 94 g ai/ha (Jordan 1995). Applying fenoxaprop-ethyl with bensulfuron increased rice yield compared with yields from bensulfuron applied alone. In Louisiana, a preliminary study indicated combinations of clomazone plus bensulfuron or halosulfuron impregnated onto urea fertilizer applied at the rice pegging (PEG) stage decreased rice foliar bleaching[7] and increased rice flatsedge (*Cyperus iria* L.) control.

Herbicide-impregnated granular fertilizers have been used successfully in several crops (Braverman 1995; Buhler 1987; Martin et al. 1989). In 1993,

[7] Webster, E. P. 2002. Personal Communication.

43,300 ha of various crops were treated in Wisconsin with herbicide-impregnated fertilizers (Rabaey and Harvey 1994). Buhler (1987) compared weed control of EPTC (S-ethyl dipropyl carbamothioate) and butylate [S-ethyl bis(2-methylpropyl)carbamothioate] applied with 95 and 285 L/ha of water to EPTC and butylate impregnated onto dry fertilizer (0-0-60) applied to no-till corn. There were no reductions in redroot pigweed (*Amaranthus retroflexus* L.), velvetleaf (*Abutilon theophrasti* Medik.), or giant foxtail (*Setaria faberi* Herrm.) control when these herbicides were impregnated onto the dry fertilizer. The objective of this study was to evaluate possible safening of clomazone to rice when clomazone plus bensulfuron or halosulfuron are impregnated onto urea and applied at 168 kg/ha at the PEG stage in a water-seeded culture. Weed control with the combinations were also evaluated.

Materials and Methods

A study was established in 2002 and 2003 at the Rice Research Station located near Crowley, La. The soil was a Crowley silt loam (fine montmorillinitic, thermic Typic Albaqualf), with 6.4 pH and 1.4% organic matter. Seedbed preparation consisted of a fall and spring disking followed by (fb) two passes in opposite directions using a two-way bed conditioner with rolling baskets and S-tine harrows set at a depth of 6 cm. Study area was laser-leveled in the winter to a slope gradient of 0.25% following initial disking. A 5-cm flood was established prior to rice planting. Plot size was 1.5 m wide by 5.2 m long.

'Cocodrie' rice was submerged in a water-filled container for 24 h, removed, and allowed to drain for 12 h to initiate germination. Pregerminated seeds were broadcast by hand into the standing flood at a seeding rate of 168 kg/ha on April 25, 2002 and April 16, 2003, respectively. After 24 h, the field was drained to allow for seedling establishment. The experimental design was a randomized complete block with four replications.

Treatments included microencapsulated (ME) clomazone[8] at 448 g/ha impregnated onto 168 kg/ha 46-0-0 (N-P-K) urea nitrogen or clomazone at 448 g/ha plus bensulfuron[9] at 10, 21, 31, and 42 g/ha or halosulfuron[10] at 13, 26, 39, and 53 g/ha impregnated onto urea nitrogen. Three comparison treatments included: 1) clomazone impregnated onto urea followed by a POST application of bensulfuron at 42 g/ha to three- to four-leaf rice, 2) clomazone impregnated onto urea followed by a POST application of halosulfuron at 53 g/ha to three- to four-leaf rice, and 3) nontreated. Crop oil concentrate[11] at 1% (v/v) was added to POST bensulfuron treatments. A nonionic surfactant[12] at 0.25% (v/v) was included with POST halosulfuron treatments. All POST herbicide treatments were applied with a CO_2-pressurized backpack sprayer set to deliver 140 L/ha spray volume at 186 Kpa.

The herbicide coated with fertilizer was mixed for 5 minutes in an Imer Minuteman Portable Electric 0.14 m^3 Concrete Cement Mixer[13] to ensure adequate coating of the herbicide onto the fertilizer. A 59 ml sample of clomazone was impregnated onto 7968 g of urea using the cement mixer. A sample of 798 g of the clomazone impregnated urea was weighed for each treatment and placed in the mixer. Bensulfuron and halosulfuron were weighed out to 0.084, 0.168, 0.246, and 0.331 g and mixed into 10 ml water. One ml of each herbicide

[8] Clomazone herbicide label. FMC Corporation, 1735 Market Street, Philadelphia, PA 19103.

[9] Londax herbicide label. E. I. du Pont de Nemours and Company, Agricultural Products, Wilmington, Delaware 19898.

[10] Permit herbicide label. Monsanto Agricultural Company, St. Louis, Missouri 63167.

[11] Crop oil concentrate Agri-Dex® is a nonionic spray adjuvant consisting of a blend of heavy range paraffin base petroleum oil, polyol fatty acid esters, and polyethoxylated derivatives. Helena Chemical Company. 6075 Poplar Ave., Suite 500, Memphis, TN 38119.

[12] Nonionic surfactant Latron AG-98® is a mixture of alkylaryl polyoxyethylene glycols. Rohm and Haas. 100 Independence Mall West, Philadelphia, PA 19106.

[13] Imer USA, Inc. 207 Lawrence Avenue, South San Francisco, CA 94080.

solution was blended with the clomazone impregnated urea in the mixer. A 133 g sample of the herbicide/fertilizer mixture was broadcasted by hand at a rate of 168 kg/ha at the PEG stage of rice on May 1, 2002 and April 28, 2003. The PEG stage refers to the growth of the rice at which the primary root penetrates the soil surface, usually occurring 4 to 7 d after planting. The nontreated received 168 kg/ha non-impregnated urea.

Permanent flood was established 24 hrs after clomazone PEG treatments were applied and was maintained until 2 weeks prior to harvest. Soil fertility management consisted of 280 kg/ha of 7-21-21 (N-P-K) fertilizer preplant and 280 kg/ha of 46-0-0 (N-P-K) urea nitrogen immediately before permanent flood. Standard agronomic and pest management practices were employed during the growing season to maximize yield. Midseason applications of a package mixture[14] of 1.68 kg ai/ha propanil [N-(3,4-dichlorophenyl) propanamide] plus 1.68 kg ai/ha molinate (S-ethyl hexahydro-1H-azepine-1-carbothioate) plus halosulfuron at 42 g/ha, in 2002 and cyhalofop[15] {(R)-2-[4-(4-cyano-2-fluorophenoxy)phenoxy]propanoic acid} at 313 g ai/ha plus halosulfuron at 42 g/ha in 2003, were applied before permanent flood establishment when rice was at the four- to five-leaf stage. These treatments were applied to help maintain area following weed control evaluations to guarantee rice harvestability.

Visual estimates of percent rice bleaching or weed control were determined on a scale of 0 to 100%, where 0 = no chlorosis/bleaching or no weed control and 100 = total chlorosis or total plant bleaching or total weed control. Rice bleaching data were obtained at 7, 21, and 35 d after PEG (DAPEG). Barnyardgrass, broadleaf signalgrass, and rice flatsedge control

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[14] Arrosolo herbicide label. RICECO Corporation, 5100 Popular Avenue, Suite 2428, Memphis, TN 38173.

[15] Clincher herbicide label. Dow AgroSciences LLC, 9330 Zionsville Road, Indianapolis, IN 46268.

were evaluated 14, 21, and 28 DAPEG. Plant height was recorded 14 and 21 DAPEG and at harvest from the soil surface to the tip of the longest leaf or the extended panicle at maturity. The average height of two plants per plot was considered as the height of the experimental unit. Rice stand was recorded 21 DAPEG by counting the number of tillers in a randomly selected 0.065 m^2 area. Final rice stand was converted to tillers/m^2. Rice grain was machine harvested on August 22, 2002 and August 18, 2003 with a small-plot combine. Final rice yield was adjusted to 12% moisture.

Final data for rice bleaching, weed control, rice stand, rice height, and rough rice grain yield were subjected to the Mixed Procedure of SAS (SAS Institute 1999). Years, replication (nested years), and all interactions containing either of these effects were considered random effects; treatment was considered a fixed effect. Considering year or combination of year and location as environments or random effects permits inferences about treatments to be made over a range of environments (Carmer et al. 1989; Hager et al. 2003). Type III statistics were used to test all possible effects of fixed factors. Least square means were used for mean separation at $p \leq 0.05$.

Results and Discussion

Since a clomazone treatment effect was significant for rice bleaching at 7 and 21 DAPEG, plant height at 14 DAPEG and harvest, population at 21 DAPEG, and rice grain yield, tables were established to reflect these effects.

At 7 DAPEG, clomazone applied alone onto urea at PEG bleached rice foliage 42% (Table 3.1). However, foliar bleaching was 23 to 30% when bensulfuron or halosulfuron were impregnated on the same fertilizer granule with clomazone. There were no differences in bleaching between treatments with bensulfuron applied at different rates to the PEG stage. Clomazone plus halosulfuron at 39 g/ha injured rice 23%. Webster et al. (2002) reported similar results with clomazone impregnated onto ammonium sulfate, urea, or a

Table 3.1. Rice foliar bleaching at 7 d after applying pegging treatments consisting of clomazone plus bensulfuron or halosulfuron combinations impregnated onto 168 kg/ha of 46-0-0 (N-P-K) urea nitrogen fertilizer and p-values to compare bleaching between treatments.

			Bensulfuron (g ai/ha)				Halosulfuron (g ai/ha)				
Herbicide[a]	Rate	Timing	10	21	31	42	13	26	39	53	Bleaching
	g ai/ha		$p \geq \|t\|$[b]								%[c]
Clomazone	448	PEG	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	42 a
+ Bensulfuron	10	PEG		0.8692	0.8692	0.8692	0.5104	1.0000	0.0146	0.1014	28 bc
	21	PEG			1.0000	1.0000	0.6215	0.8692	0.0093	0.1014	29 bc
	31	PEG				1.0000	0.6215	0.8692	0.0093	0.1014	29 bc
	42	PEG					0.6215	0.8692	0.0093	0.1014	29 bc
+ Halosulfuron	13	PEG						0.5104	0.0021	0.0338	30 bc
	26	PEG							0.0146	0.1400	29 bc
	39	PEG								0.3240	23 d
	53	PEG									25 cd

[a] Bensulfuron and halosulfuron (PEG) impregnated onto urea with clomazone.
[b] Compare bleaching means using the p-values in the table.
[c] Means followed the same lowercase letter were not significant according to the t-test on difference of least square means at $P \leq 0.05$.

50:50 blend of ammonium sulfate and urea fertilizer injured rice 20 to 26% at 10 DAPEG. At 21 DAPEG, foliar bleaching with all treatments was reduced compared with that observed at 7 DAPEG (Table 3.2), indicating that rice was recovering from the initial bleaching caused by clomazone. Foliar bleaching caused by clomazone applied alone was 21%, which was greater than clomazone plus bensulfuron or halosulfuron combinations. Foliar bleaching was 7 to 11% with any of the treatments containing bensulfuron or halosulfuron. Foliar bleaching was less than 5% for all herbicide treatments by 35 DAPEG (data not shown). This response was similar to drill-seeded rice treated with clomazone at 0.34 and 0.67 kg/ha (Scherder 2000). Barnyardgrass control at 14, 21, and 28 DAPEG was 92 to 96% regardless of the herbicide treatment (Table 3.3). Previous research indicates that clomazone provides excellent barnyardgrass control (Williams and Burns 1999.) Barnyardgrass control was not reduced when treated with bensulfuron or halosulfuron impregnated with clomazone on urea or when applied POST following a PEG clomazone application.

Broadleaf signalgrass control was greater than 90% with all herbicide mixtures at all rating dates (Table 3.3). Burns and Williams (1999) noted 91 and 97% broadleaf signalgrass control with clomazone at 0.56 to 0.67 kg/ha in drill-seeded rice.

At 14 DAPEG, rice flatsedge (*Cyperus iria* L.) control was 41% with a single application of clomazone PEG and 0% by 28 DAPEG (Table 3.3). This is similar to control observed by Webster et al. (2002) with clomazone impregnated on to 50:50 blend of ammonium sulfate and urea. At 14 DAPEG, there were no differences in rice flatsedge control with any impregnated urea combination of clomazone plus bensulfuron or halosulfuron applied PEG. The POST treatments were applied at 14 DAPEG, in both years. The lack of rice flatsedge control at 14 DAPEG was from a single application of clomazone prior to the application of bensulfuron or halosulfuron. At 21 DAPEG bensulfuron at 10 g/ha controlled rice flatsedge less than the other PEG

Table 3.2. Rice foliar bleaching at 21 d after applying pegging treatments consisting of clomazone plus bensulfuron or halosulfuron combinations impregnated onto 168 kg/ha of 46-0-0 (N-P-K) urea nitrogen fertilizer and p-values to compare bleaching between treatments.

			Bensulfuron (g ai/ha)				Halosulfuron (g ai/ha)				
Herbicide[a]	Rate	Timing	10	21	31	42	13	26	39	53	Bleaching
	g ai/ha		$p \geq \lvert t \rvert$[b]								%[c]
Clomazone	448	PEG	0.0008	0.0006	<0.0001	0.0002	0.0006	0.0006	<0.0001	<0.0001	21 a
+ Bensulfuron	10	PEG		0.9345	0.1484	0.7220	0.9128	0.9128	0.2628	0.5115	11 b
	21	PEG			0.1726	0.7843	0.9782	0.9782	0.2992	0.5656	11 b
	31	PEG				0.2746	0.1813	0.1813	0.7426	0.4278	7 b
	42	PEG					0.8054	0.8054	0.4439	0.7634	10 b
+ Halosulfuron	13	PEG						1.0000	0.3120	0.5842	11 b
	26	PEG							0.3120	0.5842	11 b
	39	PEG								0.6418	8 b
	53	PEG									9 b

[a] Bensulfuron and halosulfuron (PEG) impregnated onto urea with clomazone.
[b] Compare bleaching means using the p-values in the table.
[c] Means followed the same lowercase letter were not significant according to the t-test on difference of least square means at $P \leq 0.05$.

Table 3.3. Weed control at 14, 21, and 28 d after applying pegging treatments with clomazone plus bensulfuron or halosulfuron combinations impregnated onto 168 kg/ha of 46-0-0 (N-P-K) urea nitrogen fertilizer.

			Weed control								
			Barnyardgrass			Broadleaf signalgrass			Rice flatsedge		
Herbicide[a]	Rate	Timing	14	21	28	14	21	28	14	21	28
	g ai/ha		%[b]								
Clomazone	448	PEG	93 cd	94 abc	94 ab	93 abc	95 ab	95 ab	41 c	65 d	0 d
+ Bensulfuron	10	PEG	94 bc	92 bc	91 b	95 ab	96 a	90 bc	82 a	75 cd	76 c
	21	PEG	95 ab	95 ab	95 a	93 abc	95 ab	95 a	86 a	86 abc	91 a
	31	PEG	95 ab	93 bc	96 a	92 abc	92 c	90 bc	87 a	89 ab	81 bc
	42	PEG	94 bc	95 ab	95 a	93 abc	94 abc	94 abc	84 a	90 ab	91 a
+ Halosulfuron	13	PEG	96 a	97 a	95 a	94 ab	93 bc	94 abc	92 a	95 a	94 a
	26	PEG	96 ab	95 ab	94 ab	93 abc	95 ab	93 abc	93 a	94 a	92 a
	39	PEG	96 ab	95 ab	95 a	94 ab	96 a	95 a	93 a	95 a	95 a
	53	PEG	96 a	94 abc	95 a	95 a	95 ab	94 abc	94 a	94 a	95 a
fb Bensulfuron	42	POST	92 d	94 abc	93 ab	91 bc	94 abc	92 abc	55 b	66 d	88 ab
fb Halosulfuron	53	POST	93 cd	96 ab	94 ab	92 abc	95 ab	94 abc	36 c	81 bc	87 ab

[a] Bensulfuron and halosulfuron (PEG) impregnated onto urea with clomazone; bensulfuron and halosulfuron postemergence applied 14 DAPEG.
[b] Means followed the same lowercase letter were not significant according to the t-test on difference of least square means at $P \leq 0.05$.

treatments containing bensulfuron or halosulfuron. The level of rice flatsedge control observed with the lower bensulfuron rate, indicates this rate may be inadequate for control. Halosulfuron impregnated onto urea with clomazone controlled rice flatsedge 94 to 95%, regardless of rate. At 28 DAPEG bensulfuron at 10 and 31 g/ha PEG controlled rice flatsedge 76 and 81%, respectively, compared with 91 to 95% control with all other impregnating treatments containing bensulfuron or halosulfuron. Most of the clomazone plus bensulfuron or halosulfuron combinations on urea controlled barnyardgrass, broadleaf signalgrass, and rice flatsedge greater than 91% at 28 DAPEG. This control was comparable with clomazone applied PEG fb bensulfuron or halosulfuron applied POST. Halosulfuron applied POST at 67 g/ha controlled rice flatsedge sedge 100% (Williams and Burns 1999). The combination of the herbicides together broadened the weed control spectrum by controlling grasses and rice flatsedge and reduced the number of applications needed for total control.

At 14 DAPEG, a single application of clomazone increased plant height compared with plants receiving clomazone plus bensulfuron or halosulfuron impregnated on urea (Table 3.4). Height of the clomazone treated plants was similar to the nontreated. This increase in plant height may be due to illiation of the plants treated with a single application of clomazone. In contrast, Vencill et al. (1989) found clomazone treated corn to be shorter than the nontreated. At harvest plant height was similar for all rice treated with clomazone or clomazone plus bensulfuron or halosulfuron (Table 3.4).

At 21 DAPEG, the number of tillers/m^2 was 420 to 610 for rice treated with all herbicide treatments (Table 3.4). The number of rice tillers was less with a single application of clomazone applied PEG, compared with clomazone plus halosulfuron at 13 or 26 g/ha PEG. Jordan et al. (1998)

Table 3.4. Plant height, total plant population, and grain yield for rice treated with clomazone plus bensulfuron or halosulfuron combinations impregnated onto 168 kg/ha of 46-0-0 (N-P-K) urea nitrogen fertilizer and applied to pegging rice.

			Height		Population	Grain Yield
Herbicide[a]	Rate	Timing	14 DAPEG	Harvest	21 DAPEG	
	g ai/ha		——— cm[b] ———		tillers/m^{2,b}	kg/ha[b]
Clomazone	448	PEG	29 a	95 a	480 def	6500 ab
+ Bensulfuron	10	PEG	26 bcd	97 a	480 def	6280 b
	21	PEG	26 bcd	97 a	580 a-d	6210 b
	31	PEG	26 bcd	97 a	530 a-e	6150 b
	42	PEG	24 d	95 a	500 def	6660 ab
+ Halosulfuron	13	PEG	25 cd	99 a	610 abc	5970 b
	26	PEG	24 d	96 a	630 a	6070 b
	39	PEG	24 d	99 a	540 a-e	6630 ab
	53	PEG	21 e	97 a	470 ef	7230 a
fb Bensulfuron	42	POST	28 ab	97 a	520 b-f	6520 ab
fb Halosulfuron	53	POST	26 bcd	96 a	420 f	6520 ab
Nontreated			29 a	89 b	620 ab	4520 c

[a] Bensulfuron and halosulfuron (PEG) impregnated onto urea with clomazone; bensulfuron and halosulfuron postemergence applied 14 DAPEG.
[b] Means followed the same lowercase letter were not significant according to the t-test on difference of least square means at $P = 0.05$.

noted stand reductions in both drill- and water-seeded experiments in Crowley, Louisiana with clomazone at 0.56 to 2.2 kg/ha. Clomazone at 1.12 kg/ha applied PRE also caused a stand reduction to Earl, 'LL-401', and Wells at 34 DAT (Zhang et al. 2003).

There were no yield differences with clomazone alone or clomazone plus bensulfuron or halosulfuron applied PEG or POST (Table 3.4). Rice yield was greater with any herbicide treatment compared to the nontreated. Beaty et al. (1991) reported severe rice bleaching from direct applications of clomazone at 1.1 kg/ha but no reduction in grain yield. Other reports evaluating clomazone in rice reported clomazone treated rice resulted in higher yields than the nontreated (Mitchell and Hatfield 1996; Webster et al. 1999). Rice has the ability to recover from early season injury and stand reductions. An initial reduction in plant population due to clomazone may result in greater tiller production, which could be a possible reason the rice treated with clomazone alone yielded similar to those receiving bensulfuron or halosulfuron impregnated on urea with clomazone.

These results indicate that bensulfuron or halosulfuron can be impregnated with clomazone onto the same fertilizer carrier to reduce clomazone injury in the form of bleaching and stand and height reductions. Foliar bleaching decreased from 42% to less than 30% with the addition of bensulfuron or halosulfuron to clomazone at 7 and 21 DAPEG. All herbicides treatments controlled barnyardgrass and broadleaf signalgrass greater than 90% through 28 DAPEG. Clomazone alone did not control rice flatsedge by 28 DAPEG; however, the addition of any rate of bensulfuron or halosulfuron applied PEG increased control to 76% and greater. The PEG treatments of bensulfuron and halosulfuron were comparable to these herbicides applied POST. By applying the PRE and POST herbicides on the same fertilizer, an application cost was saved while achieving similar control to those herbicides applied separately. Any rate of these two herbicides could be used with clomazone in a weed management program in water-seeded rice. Higher rates of bensulfuron and halosulfuron may be needed to control rice flatsedge under certain situations and to meet the labeled rate of each herbicide. The number of tillers/m^2 was greater for rice plants receiving clomazone plus halosulfuron at 13 and 26 g/ha applied PEG compared with rice plants receiving clomazone applied alone or fb bensulfuron and halosulfuron POST. Despite early season injury caused by clomazone, there were no differences in rice yield between any treatments receiving clomazone. Rice yield was less for the nontreated compared with any clomazone treatment.

In conclusion, the impregnation of bensulfuron or halosulfuron with clomazone can be useful in a weed management program in water-seeded rice. The impregnation of the two herbicides with clomazone not only broadens the weed control spectrum, but also decreases early season rice injury. In addition, this practice can help reduce production costs and save time by eliminating a trip across the field. The PEG application tends to cause greater injury to water-seeded rice. However, the early herbicide applications, such as PEG treatments, aid in controlling early weed pressure and reduce weed competition.

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CHAPTER 4

EFFECT OF BENSULFURON AND HALOSULFURON ON CLOMAZONE AS REFLECTED BY RICE (*ORYZA SATIVA* L.) BLEACHING AND CHLOROPHYLL CONTENT

Introduction

The leaves of susceptible plants treated with clomazone {2-[(2-chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidinone} lose pigmentation and appear bleached and white (Duke et al. 1985). It has been reported that clomazone causes chloroplasts damage and reduces chlorophyll and carotenoid synthesis in susceptible plants (Duke and Paul 1986; Duke et al. 1991; Norman et al. 1990b; Scott and Weston 1992). Chlorophyll accumulation in clomazone treated leaf tissues after 24 hr of continuous white light was approximately half that of the control on a fresh weight basis (Duke and Kenyon 1986).

Zhang et al. (2004) reported that rice cultivars differed in response to clomazone. Compared with long-grain cultivars, medium grain cultivars were less tolerant to clomazone. Several researchers have speculated that different sites of action or differences in the sensitivity of a clomazone site of action may be responsible for differential tolerance among species (Norman et al. 1990a; Salzman et al. 1992; Weimer et al. 1992; Weston and Barrett 1989).

Hydroponic studies have been used to evaluate variation in soybean [*Glycine max* (L.) Merr.] cultivar tolerance to AC 263,222 {(±)-2,4,5-dihydro-4-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid} (Wixson and Shaw 1991), chlorimuron {2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid} and imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid} (Newsom and Shaw 1992), and metribuzin [4-amino-6-*tert*-butyl-3-(methylthio)-as-triazine-5(4H) one] (Barrentine et al.

1976). This technique rapidly screens cultivar tolerance by using shoot and root biomass reductions, along with visual injury symptoms (Newsom and Shaw 1992). Salzman et al. (1992) grew soybean plants in a nutrient solution to determine the effects of clomazone plus metribuzin or clomazone plus linuron [*N*-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea)] on root uptake, partitioning, and metabolism. Root uptake and partitioning of clomazone in soybean differed compared with clomazone plus metribuzin. The metabolism of metribuzin and linuron is altered in soybean with the addition of clomazone, leading to increased phytotoxicity and synergistic interactions. Weimer et al. (1991) evaluated soybean and velvetleaf (*Abutilon theophrasti* Medik.) grown in nutrient solutions containing ^{14}C-clomazone at 1nM to 500 µM. Clomazone concentrations in nutrient solutions causing a 50% reduction in fresh shoot weights were 325 and 2 µM for soybean and velvetleaf, respectively. Root uptake of ^{14}C-clomazone from nutrient solution and translocation to shoots was similar for the two species regardless of concentration.

Synergistic and antagonistic effects are important consequences of herbicides in mixture (Blouin et al. 2004). In order to determine if the combination of two herbicides is synergistic or antagonistic, the two herbicides must be applied alone and in mixture in the same study (Colby 1967). Clomazone metabolism has been reduced by the addition of organophosphate insecticides, disulfoton {*O*,*O*-diethyl S-[2-(ethylthio)ethyl] phosphorothithiote} and phorate {*O*,*O*-diethyl S-[(ethylthio)methyl] phosphorodithioate}, indicating a clomazone metabolite may be more toxic to cotton (Culpepper et al. 2001). Therefore the objective of this study was to evaluate the interactive effects of bensulfuron {2-[[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]methyl]benzoic acid} and halosulfuron {3-chloro-5-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl] amino]sulfonyl]-1-methyl-1H-pyrazole-4-carboxylic acid} on clomazone by evaluating rice foliar bleaching and chlorophyll content.

Materials and Methods

A laboratory study was conducted in 2003 at Louisiana State University in Baton Rouge, La. to evaluate the interactive effects of bensulfuron and halosulfuron on clomazone in terms of rice foliar bleaching and chlorophyll content. The experimental design was a completely randomized design with a three factor factorial arrangement of treatments with five replications and the experiment was repeated. Factor A consisted of clomazone at 0 or 1.227 µg ai/ml (672 g ai/ha). Factor B consisted of bensulfuron at 0.0276 µg ai/ml (42 g ai/ha), or halosulfuron at 0.0345 µg ai/ml (53 g ai/ha) or no bensulfuron or halosulfuron. Herbicide solutions were pipetted into 150 Erlenmeyer flasks and the rice plants were grown in a hydroponic solution. Factor C consisted of rice cultivars including medium-grain 'Bengal', long-grain 'Cocodrie', and short-grain 'Pirogue'. Methods for germination were modeled after procedures by Webster et al. (2003). The seeds were soaked in distilled water for 24 hours and drained to initiate the germination process. Viable pregerminated seed were surface disinfected with a 50:50 chlorine bleach:distilled water solution (5.25% sodium hypochlorite) for 10 minutes and rinsed with distilled water for one minute to control organisms that may cause seedling disease. The pregerminated seeds were then placed in a 9.0 cm diameter plastic petri dish between two sheets of nontreated Anchor[16] germination paper to allow for seedling development. A 10 ml aliquot of carboxin (5,5-dihydro-2-methyl-*N*-phenyl-1,4-oxathiin-3-carboxamide) plus thiram (tetramethylthiuram disulfide) solution[17] (1:1 ratio) with a combined

[16] Anchor Paper Co., 480 Broadway Street, St. Paul, MN 55101.

concentration of 7.5 ml/L was added to each petri dish to reduce seedling diseases. The seeds were grown in petri dishes for 5 d at a constant 28 C to allow for seedling development. The germinating seeds were grown under a florescent growth light containing twelve 117.8 cm florescent bulbs with an output of 34.0 watts and 2279 lumens. Preliminary testing indicated longer germination and seedling development requirements for the short-grain Pirogue cultivar than the other two cultivars; therefore, Bengal was placed in the petri dishes one day later and Cocodrie was placed five days later than Pirogue.

Healthy seedlings of uniform size were selected from the petri dishes on June 10 and July 31, for the first and second experiment, respectively. A single seedling approximately 4 to 5 cm in length was placed at the base of a stemless 24 by 4.5 mm diameter funnel with the root extending thru the 4.5 mm end. Seedlings were held in place by a small amount of cotton at the 4.5 mm end and by filling the funnel with 3.0 g of sterilized masonry sand to aid in plant support. The funnel was placed onto the top of a 150 ml Erlenmeyer flask allowing the roots of the plant to extend into water containing the appropriate herbicide concentration. All flasks were wrapped with aluminum foil to prevent herbicide photodegredation and reduce alga growth. Methods for seedling growth in flasks were modeled after procedures by Weimer et al. (1991). One ml of Miracle Grow[18] fertilizer was pipetted at 0.79 g of fertilizer/1 L of water into individual flasks every 6 d. This is 20% of the manufacturers recommended rate. Fertilizer rate was decreased to prevent the fertilizer from antagonizing the herbicide solution, but help provide basic essential nutrients for the young rice plants. Herbicide treatments were

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[17] Vitavax-200 Fungicide label, Gustafson LLC, 1400 Preston Rd. Suit 400, Plano, TX, 75093.

[18] Miracle-Gro is an all purpose plant food consisting of 15-3-15 (N-P-K). Scotts Miracle-Gro Products, Inc., 14111 Scottslawn Road, Maryville OH 43041.

pipetted into the flasks 3 d after the plants were initially placed into the flasks. This allowed the rice seedling to acclimate to the new environment. The plants were grown under the same florescent growth light as previously discussed for 12/12 h alternate light/dark conditions for 21 d.

Visual estimates of rice bleaching were determined at 21 d after treatment (DAT) on a scale of 0 to 100%, where 0 = no bleached or chlorotic/necrotic tissue and 100 = complete bleaching or plant death. At 21 DAT, rice plants were harvested, roots were removed, and the weight of the shoots and leaves recorded. The tissue was immediately dipped in liquid nitrogen (N_2) for 5 seconds and placed in sealed plastic bags, which were then stored in a freezer at -20 C until chlorophyll analysis was conducted.

Procedures similar to Arnon (1949) were used to extract chlorophyll from rice shoots. Individual plants were ground for 2 minutes in 5 ml of an 8:2, acetone:distilled water solution. The ground material was filtered through Whatman[19] #1 filter paper into a 25 ml volumetric flask to extract the chlorophyll and filter out solid plant material. An additional 10 ml of the acetone:distilled water solution was used to wash the filter paper clean of any chlorophyll residue. The filtered solution was brought to a total volume of 25 ml by addition of 8:2, acetone:distilled water solution. Samples were analyzed immediately for chlorophyll content.

Chlorophyll a and Chlorophyll b content were measured using a Spectronic Genesys 5 Spectrophotometer[20] at wavelengths of 663 nm and 645 nm, respectively. Chlorophyll content was expressed on a µg chlorophyll per gram fresh weight basis.

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[19] Whatman International Ltd, Springfield Mill, James Whatman Way, Maidstone, Kent, ME 14 2LE, UK.

[20] Spectronic Genesys 5 Spectrophotometer. Milton Roy Company, 201 Ivyland Road, PA 18974-0577.

Rice bleaching data were analyzed using a non-linear mixed model methodology for potential herbicide interactions (Blouin et al. 2004). Interactions between clomazone and other herbicides were calculated by the mathematical method described by Colby (1967). An expected value was calculated by using the formula: $E = X + Y - (XY/100)$, where E is the expected response, X and Y are weed control by herbicide A and B applied alone, respectively. Expected and observed values were compared using p-values generated by NLMIXED T test (Blouin et al. 2004). If the observed response for the herbicide combination was significantly less than the expected value, the combination was determined to be antagonistic; if significantly more than the expected value, the combination was determined to be synergistic; the combination was additive when there was not a significant difference between the observed and the expected responses. In this study an antagonistic response would be indicative of a safening effect.

Change of herbicide interaction over time or rating dates is reflected by linear and quadratic contrasts for equally spaced effects (Blouin et al. 2004). Statistical significance of the change in herbicide interaction over time is determined by p-values at 0.05 level. Negative or positive values for linear (L) effects indicate an increase or decrease, respectively, in antagonism over time. Negative or positive values for quadratic (Q) effects indicate a convex or concave change, respectively, in antagonism over time. Due to the fact that chlorophyll content and shoot weight varied greatly among cultivars, chlorophyll and shoot weight data were analyzed separately for each cultivar and subjected to the Mixed Procedure of SAS (SAS Institute 1999). Least square means were used for mean separation at $p \leq 0.05$.

Results and Discussion

Rice foliar bleaching was less than 5% at 7 DAT for all cultivars regardless of herbicide treatment (data not shown). At 14 DAT, the observed foliar bleaching was 29 to 32%, 15 to 17%, and 34 to 37% for Bengal, Cocodrie, and Pirogue, respectively, with clomazone at 1.227 μg/ml with or without the addition of bensulfuron or halosulfuron (Table 4.1). The addition of bensulfuron or halosulfuron did not affect bleaching of Bengal or Cocodrie as indicated by an additive response. For Pirogue, the addition of bensulfuron to clomazone did not affect bleaching compared with clomazone alone; however, the addition of halosulfuron reduced foliar bleaching compared with clomazone alone, resulting in a safening effect. At 21 DAT, overall foliar bleaching increased from 36 to 56, 30 to 39, or 58 to 64% for Bengal, Cocodrie, and Pirogue, respectively. The addition of bensulfuron or halosulfuron reduced foliar bleaching of all three cultivars by clomazone and resulted in a safening affect. The increased safening response at 21 DAT compared with 14 DAT may be due to the slow activity of the ALS inhibiting herbicides used in this study. Bensulfuron and halosulfuron activity on plants is slow and not fully expressed until 21 DAT (Ahrens 1994). These results indicate that 14 d is not adequate time for bensulfuron and halosulfuron to safen rice from clomazone injury under laboratory conditions.

Change of interaction between clomazone plus bensulfuron or halosulfuron was analyzed using linear contrasts for equally spaced effects. The results indicated that the safening effect of bensulfuron on clomazone increased linearly from 14 to 21 DAT for each cultivar (Table 4.2). The linear safening effect increased for halosulfuron; however, the safening was significant only with Bengal and Cocodrie, not on Pirogue. These results further prove that it may take 21 or more days for the safening effect of bensulfuron and halosulfuron on clomazone to be fully expressed in a laboratory situation.

Table 4.1. Rice response to clomazone with and without the addition of bensulfuron and halosulfuron grown in a hydroponic solution.[a-d]

Cultivar	Mixture herbicide	Rate	Clomazone 0 µg ai/ml Observed	Clomazone 1.227 µg ai/ml Observed	Expected	P-vlaue	Response[e]
		µg ai/ml	% Bleaching	—— % Bleaching	——	p ≥ |t|	
Bengal	14 DAT						
	None		0	32	-		
	Bensulfuron	42	0	29	32	0.2409	Additive
	Halosulfuron	53	0	29	32	0.2409	Additive
	21 DAT						
	None		0	56	-		
	Bensulfuron	42	0	36	56	<.0001	Safening
	Halosulfuron	53	0	44	56	<.0001	Safening
Cocodrie	14 DAT						
	None		0	17	-		
	Bensulfuron	42	0	15	17	0.4193	Additive
	Halosulfuron	53	0	17	17	1.0000	Additive
	21 DAT						
	None		0	39	-		

(Table 4.1 continued)

	Bensulfuron	42	0	30	39	0.0005	Safening
	Halosulfuron	53	0	31	39	0.0100	Safening
Pirogue	14 DAT						
	None		0	37	-		
	Bensulfuron	42	0	36	37	0.3327	Additive
	Halosulfuron	53	0	34	37	0.0265	Safening
	21 DAT						
	None		0	64	-		
	Bensulfuron	42	0	58	64	<.0001	Safening
	Halosulfuron	53	0	58	64	0.0001	Safening

[a] Data obtained by visually estimating rice bleaching on a scale of 0 to 100, where 0 = no bleaching and 100 = complete bleaching.
[b] Values were calculated based on Modified Colby's Formula (Blouin et al. 2004).
[c] P-values are used to compare the difference between the observed and the estimated values within a row; Analysis was conducted within a variety
[d] Abbreviations, DAT, d after treatment.
[e] Response equals effect of bensulfuron or halosulfuron on activity of clomazone; safening = reduction in rice bleaching, additive = no reduction in rice bleaching.

Table 4.2. Changes in activity of clomazone with the addition of bensulfuron or halosulfuron on rice bleaching over time.[a-c]

	Mixture		Clomazone (1.227 µg ai/ml)		
Cultivar	herbicide	Rate	DAT	Obs - Est	P-value
		µg ai/ml		%	p ≥ |t|
Bengal					
	Bensulfuron	42	14	-3	0.2409
			21	-20	<.0001
			L	-17	<.0001
	Halosulfuron	53	14	-3	0.2409
			21	-12	<.0001
			L	-9	0.0040
Cocodrie					
	Bensulfuron	42	14	-2	0.4193
			21	-9	0.0005
			L	-7	0.0097
	Halosulfuron	53	14	0	1.0000
			21	-8	0.0100
			L	-8	0.0017
Pirogue					
	Bensulfuron	42	14	-1	0.3327
			21	-6	<.0001
			L	-5	0.0044
	Halosulfuron	53	14	-3	0.0265
			21	-6	0.0001
			L	-3	0.1427

(Table 4.2 continued)

[a] Abbreviations, DAT, d after treatment; L, linear contrasts of the difference between the observed and the Colby's estimated values by treatments;

[b] Values were calculated by subtracting the Modified Colby's (Blouin et al. 2004) estimated %bleaching from the observed %bleaching.

[c] P-values are used to compare the difference between the observed and the estimated values; Analysis was conducted within a variety.

Table 4.3. Effect of clomazone with and without the addition of bensulfuron and halosulfuron on rice grown in a hydroponic solution chlorophyll content and shoot weight.[a-c]

Cultivar	Mixture herbicide	Rate	Clomazone (1.227 µg ai/ml) Chlorophyll a	Chlorophyll b	Total Chlorophyll	Shoot weight
		µg ai/ml	µg/g			g
Bengal						
	None	672	15 b	42 b	57 b	0.1226 b
	Bensulfuron	42	18 b	45 b	63 b	0.1232 b
	Halosulfuron	53	17 b	42 b	59 b	0.1104 b
	Nontreated[c]		35 a	93 a	128 a	0.1341 a
Cocodrie						
	None	672	12 c	48 c	60 c	0.0982 b
	Bensulfuron	42	14 b	59 b	73 b	0.0973 b
	Halosulfuron	53	15 b	58 b	73 b	0.0944 b
	Nontreated		33 a	88 a	121 a	0.1339 a
Pirogue						
	None	672	12 b	32 b	44 b	0.0618 b
	Bensulfuron	42	14 b	35 b	49 b	0.0723 b
	Halosulfuron	53	15 b	36 b	51 b	0.0698 b
	Nontreated		37 a	97 a	134 a	0.1070 a

(Table 4.3 continued)

[a] Means within a column followed by the same letter are not significantly different at $P \leq 0.05$ according to Fisher's Protected LSD test.
[b] Lowercase letters are used to compare all treatments. Means followed the same lowercase letter were not significant according to the t-test on difference of least square means at $P = 0.05$; Analysis was conducted within a variety.
[c] Chlorophyll content expressed in µg chlorophyll/g fresh weight.

Rice shoot fresh weight was also reduced by clomazone regardless of bensulfuron or halosulfuron (Table 4.3). There were no differences among the treatments containing clomazone for all three cultivars. Previous research reported clomazone had no effect on corn fresh weight (Zea mays L.) and soybean plants grown in hydroponics at concentrations that caused significant reductions in chlorophyll content (Liebl and Norman 1991).

There were no differences in rice chlorophyll content between bensulfuron or halosulfuron applied alone compared with the nontreated cultivars (data not shown). Regardless of the addition of bensulfuron or halosulfuron, clomazone significantly reduced chlorophyll a, b, and total chlorophyll content of all three cultivars compared with the nontreated within each cultivar (Table 4.3). This indicates that chlorophyll a, b, or total chlorophyll can be used as criteria to reflect rice injury by clomazone. Chlorophyll a and b responded similarly to the clomazone treatments. However, Duke and Kenyon (1986) found chlorophyll b accumulation was more strongly reduced by clomazone than chlorophyll a. For Cocodrie, the addition of bensulfuron or halosulfuron to clomazone, increased chlorophyll a and b and total chlorophyll content compared with clomazone alone, indicating a safening effect. However, for Bengal and Pirogue only trends were observed, indicating the interaction between bensulfuron or halosulfuron with clomazone may involve more mechanisms other than chlorophyll content or take longer time to develop at the chlorophyll level.

In conclusion, these results indicate that bensulfuron and halosulfuron have a safening effect on rice injury caused by clomazone; however, the safening effect is limited since the addition of these herbicides cannot eliminate bleaching completely. Foliar bleaching from a single application of clomazone was decreased from 56% to 36 and 44% for medium-grain Bengal with the addition of bensulfuron and halosulfuron, respectively. The safening effect of bensulfuron on clomazone increased linearly from 14 to 21 DAT for all three cultivars, while the linear safening effect increased for halosulfuron only on Bengal and Cocodrie. The safening effect from bensulfuron and halosulfuron may take more than 21 d to be fully expressed due to the slow activity or mechanism of these two herbicides. In addition, rice shoot weight is not affected by the addition of bensulfuron or halosulfuron. Total chlorophyll content of Cocodrie was increased from 60 to 73 µg/g with the addition of bensulfuron or halosulfuron. Chlorophyll a and b were reduced proportionally by clomazone for all three cultivars, indicating that clomazone is not selective of chlorophyll a or b in rice. Rice is safened from injury caused by clomazone by 21 DAT for cultivars, but injury was greater and chlorophyll content was less for the medium and short grain cultivars. Field research indicated differences in cultivar tolerance to clomazone (Scherder et al. 2000; Zhang et al. 2004). The long grain cultivar displayed more tolerance to clomazone as indicated with less foliar bleaching and increased chlorophyll content.

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CHAPTER 5

SUMMARY

Two field studies were established in 2002 and 2003 to evaluate the tolerance of rice cultivars to clomazone and to evaluate the effect of clomazone plus bensulfuron or halosulfuron on rice injury and weed control in a water-seeded production system. All herbicide treatments were impregnated onto 168 kg/ha 46-0-0 (N-P-K) urea nitrogen and applied to pegging (PEG) rice. A laboratory study was also established in 2003 to evaluate the response of three rice cultivars to clomazone applied alone in a hydroponic solution or in combination with bensulfuron or halosulfuron.

Research was conducted near Crowley, Louisiana to evaluate the tolerance of six long-grain rice cultivars 'Ahrent', 'Cheniere', 'Cocodrie', 'Cypress', 'Francis', and 'Wells', one medium grain 'Bengal', and one short grain cultivar 'Pirogue' to clomazone. Clomazone was impregnated onto urea fertilizer and applied at 168 kg/ha at 0 and 896 g ai/ha. Rice foliar bleaching, population, plant height, and grain yield were evaluated. At 7 d after PEG (DAPEG), clomazone injured, in the form of foliar bleaching, Bengal and Pirogue 24 and 30%, respectively, which was greater than bleaching of Ahrent, Cheniere, Cocodrie, Cypress, Francis, Wells, and Bengal. At 14 DAPEG, Cheniere was bleached 16%, which was less than any other cultivar, except Wells.

By 56 DAPEG foliar bleaching was less than 10% for all cultivars evaluated. At 21 DAPEG, rice plant population of all cultivars treated with clomazone was less than their respective nontreated. Rice treated with clomazone was reduced in plant population from 150 to 310 tillers/m^2 compared with respective nontreateds. Rice plant height was reduced for Cypress, Francis, Wells, and Bengal compared with respective nontreated at 14 DAPEG.

There were no yield reductions with regard to the medium and long-grain cultivars when compared within a nontreated cultivar (Table 2.8). Rice yield of Pirogue treated with clomazone was 1740 kg/ha less than the nontreated. These data indicate clomazone causes rice injury, reduces stand and height for the long, medium, and short grain cultivars evaluated in this study. Despite the early season injury caused by clomazone, all cultivars except short-grain Pirogue were able to compensate and produce quality yields. Therefore clomazone should not be applied to the short-grain Pirogue rice cultivar. The rates used in this study are greater than the manufacturers recommended rates. Applying this herbicide within the labeled application rate at rice PEG should result in reduced foliar bleaching.

Research was conducted near Crowley, Louisiana to evaluate the tolerance of Cocodrie to clomazone plus bensulfuron or halosulfuron impregnated onto urea. Treatments included clomazone at 448 g/ha impregnated onto urea plus bensulfuron at 10, 31, 21, and 42 g/ha or halosulfuron at 13, 26, 39, and 53 g ai/ha. Four comparison treatments included: 1) a single application of clomazone impregnated onto urea, 2) clomazone impregnated onto urea followed by a POST application of bensulfuron at 42 g/ha on three- to four-leaf rice, 3) clomazone impregnated onto urea followed by a POST application of halosulfuron at 53 g/ha on three- to four-leaf rice, and 4) nontreated. Foliar bleaching, population, plant height, and grain yield were evaluated. Barnyardgrass [Echinochloa crus-galli (L.) Beauv.], broadleaf signalgrass [Brachiaria platyphylla (Griseb.) Nash], and rice flatsedge (Cyperus iria L.) control were also evaluated. At 7 DAPEG, clomazone applied alone onto urea at PEG bleached rice foliage 42%. However, foliar bleaching was 23 to 30% when bensulfuron or halosulfuron were impregnated on the same fertilizer with clomazone. At 21 DAPEG, foliar bleaching caused by clomazone applied alone was 21%, compared with foliar bleaching of 7 to 11% with any of the bensulfuron or halosulfuron treatments when impregnated on urea with clomazone. Foliar bleaching was less than 5% for all herbicide treatments by 35 DAPEG.

Clomazone treated plant height was similar to the nontreated. At harvest, plant height was similar for all rice treated with clomazone or clomazone plus bensulfuron or halosulfuron. At 21 DAPEG, the number of tillers/m^2 was 420 to 610 for rice treated with all herbicide combinations.

Most of the clomazone plus bensulfuron or halosulfuron combinations impregnated on urea controlled barnyardgrass and broadleaf signalgrass at 28 DAPEG. Clomazone applied alone provided did not control rice flatsedge by 28 DAPEG; however, control was greater than 76% with the addition of bensulfuron or halosulfuron applied PEG. The number of rice tillers was less with a single application of clomazone applied PEG, compared with clomazone plus halosulfuron at 13 and 26 g/ha PEG. There were no yield differences when rice was treated with clomazone alone or clomazone with any combination of bensulfuron or halosulfuron applied PEG or POST. Rice yield with any herbicide treatment was greater than the nontreated.

These results indicate that bensulfuron and halosulfuron can be impregnated with clomazone onto the same fertilizer carrier to reduce clomazone injury in the form of bleaching and stand and height reductions. By applying clomazone and bensulfuron or halosulfuron on the same fertilizer, an application cost was saved while achieving similar control to those herbicides applied separately. The impregnation of bensulfuron or halosulfuron with clomazone can be useful in a weed management program in water-seeded rice.

A laboratory study was conducted in 2003 at Louisiana State University in Baton Rouge, La. to evaluate the interactive effects of bensulfuron or halosulfuron on clomazone in terms of rice foliar bleaching and chlorophyll content. Clomazone applied alone at 0 and 1.227 µg/ml (672 g/ha), or in combination with bensulfuron at 0.0276 µg ai/ml (42 g ai/ha), or halosulfuron at 0.0345 µg ai/ml (53 g ai/ha). Bensulfuron and halosulfuron were also applied alone. Rice cultivars evaluated included medium-grain 'Bengal', long-grain 'Cocodrie', and short-grain 'Pirogue'. Herbicides solutions were placed in Erlenmeyer flasks and the rice plants were grown in a hydroponic solution. Foliar bleaching and chlorophyll content were evaluated. In this study an antagonistic response would be equivalent to a safening effect or reduction in foliar bleaching. At 14 DAT, the observed foliar bleaching was 29 to 32%, 15 to 17%, and 34 to 37% for Bengal, Cocodrie, and Pirogue, respectively, with clomazone at 1.227 µg/ml with or without the addition of bensulfuron or halosulfuron. For Pirogue, bensulfuron did not affect bleaching; however, the addition of halosulfuron reduced bleaching, resulting in a safening effect. At 21 DAT, overall bleaching increased with bleaching from 36 to 56, 30 to 39, or 58 to 64% for Bengal, Cocodrie, the addition and Pirogue, respectively. Both bensulfuron and halosulfuron reduced bleaching of all three cultivars by clomazone and resulted in a safening affect. Rice shoot fresh weight was also reduced by clomazone regardless of bensulfuron or halosulfuron. There were no differences among the treatments containing clomazone for all three cultivars. Regardless of bensulfuron or halosulfuron, clomazone significantly reduced chlorophyll a, b, and total chlorophyll content of all three cultivars compared with the nontreated within each cultivar. For Cocodrie, addition of bensulfuron or halosulfuron to clomazone, increased chlorophyll a and b and total chlorophyll content compared with clomazone alone, indicating a safening effect. However, for Bengal and Pirogue chlorophyll content was not increased by the addition of the bensulfuron or halosulfuron.

Foliar bleaching caused by clomazone was reduced by the addition of bensulfuron or halosulfuron to the same hydroponic solution. These results indicate that bensulfuron and halosulfuron have a safening effect on rice injury caused by clomazone; however, the safening effect is limited since the addition of these herbicides cannot completely eliminate bleaching. Chlorophyll content was increased only in long-grain Cocodrie by the addition of bensulfuron and halosulfuron to clomazone.

In conclusion, these results indicate the potential use of clomazone when applied on different cultivars in water-seeded rice. Many long-grain cultivars evaluated in this study are tolerant of clomazone. Results indicate that the medium-grain Bengal may be less tolerant than many long-grains; however, rice recovered from the early season injury and produced yields similar to the nontreated Bengal. Clomazone can be impregnated onto urea and applied PEG at the labeled rate. The addition of bensulfuron and halosulfuron to clomazone can safen rice from clomazone injury. These herbicides also reduce the effects of clomazone on chlorophyll content of Cocodrie. Bensulfuron and halosulfuron also broaden the weed control spectrum of clomazone, and these combinations of clomazone plus bensulfuron or halosulfuron can reduce production costs and save time by eliminating a herbicide application.

VITA

Christopher Ray Mudge was born on September 3, 1979, the eldest of two children to Alvin and Wanda Mudge in Alexandria, Louisiana. He was raised in the small rural farming community of Branch, Louisiana. During his elementary and high school years, he was active with 4-H and FFA where he participated in livestock shows and horticulture and plant science judging contests. After graduation from Iota High School in 1997, he enrolled at Louisiana State University and majored in agronomy. While an undergraduate he was active in the agronomy and collegiate 4-H clubs where he served as President and Vice-President, respectively. In December 2002, he graduated with a Bachelor of Science degree in agronomy. In January 2002, Chris began his graduate career in Weed Science under the direction of Dr. Eric P. Webster. He is currently a candidate for the degree of Master of Science in agronomy with a concentration in weed science. Upon graduation in May 2004, Chris plans to pursue his doctorial degree.