INFLUENCE OF ENVIRONMENTAL PARAMETERS ON PENOXSULAM CONTROL OF ALLIGATORWEED (*Alternanthera philoxeroides*) IN RICE (*Oryza sativa*)

A Dissertation

by

SAMUEL DUANE WILLINGHAM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2008

Major Subject: Agronomy

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May 2008

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ABSTRACT

Influence of Environmental Parameters on Penoxsulam Control of Alligatorweed (*Alternanthera philoxeroides*) in Rice (*Oryza sativa*). (May 2008)

Samuel Duane Willingham, B.S.; M.S., University of Florida

Chair of Advisory Committee: Dr. J. M. Chandler

Alligatorweed is a perennial plant which reproduces vegetatively and has spread from waterways into canals and ultimately into rice fields of Louisiana and Texas. Penoxsulam is a new acetolactate synthase (ALS) inhibiting broad-spectrum herbicide that was registered for rice in 2005. Previous research on alligatorweed control has focused mainly in aquatic areas and in the rice producing regions of Louisiana with little success. Research is limited using penoxsulam for alligatorweed control in rice production and results vary between year and location. Variability could be due to growth habit and resource allocation of this perennial species. Therefore, field and laboratory experiments were conducted from 2004 to 2007 to: 1) evaluate the effects of select rice herbicides on alligatorweed control, 2) determine the absorption and translocation efficiency and the effect of propanil on penoxsulam in alligatorweed 3) access the environmental effects of temperature on penoxsulam efficacy and determine application timing to avoid antagonism with propanil and, 4) evaluate the effects of flood timing and rice cultivars on rice root stunting and plant foliar injury from penoxsulam applications.

Alligatorweed control was obtained from penoxsulam or bispyribac-sodium applied alone; however, mixtures with propanil were antagonistic. Day temperatures at 21 C increased efficacy of penoxsulam compared to 27 and 30 C day temperatures. Delaying propanil applications 3 days following penoxsulam applications were required at 21 and 27 C and 10 days at 30 C in order to avoid antagonism. Alligatorweed absorbed up to 33% of penoxsulam when applied alone, but most was retained in treated leaves (29%). Propanil reduced penoxsulam absorption into alligatorweed with only 22% of total penoxsulam recovered being absorbed by alligatorweed. More than 50% remained on the leaf surface of the treated leaf. Previous research has indicated root stunting of rice plants from ALS inhibiting herbicides. When various rice varieties were permanently flooded one week after herbicide application of penoxsulam, root stunting was greater compared to delaying flood establishment 7 or 14 days after treatment. Significant root stunting, however, did not affect rice yield.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.] is a member of the Amaranthaceae family. It is a noxious perennial herbaceous, aquatic or terrestial plant with horizontal to ascending stems 1 m long that root at the nodes (Julien and Broadbent 1980). The aquatic form has hollow, floating, emergent and submerged stems whereas terrestrial forms have solid stems. Typically, plants grow in shallow water rooted in soil and form dense interwoven floating mats that extend over the surface of deeper water. Floating mats can break away and colonize new sites. Reproduction is entirely vegetative with two viable axillary buds capable of growth at all stem nodes. On land, cultivation may drag stolon pieces to uninfested areas and with partial soil contact, produce new plants increasing infestation (Parsons and Cuthbertson 2001). Plant biomass can double in the field in approximately 50 d during the summer (Brown and Spencer 1973).

Mature plants have simple or branched dark green stems, lacking hairs, up to 70 cm long (Julien and Broadbent 1980). Leaves are opposite, more or less equal at the node, sessile or with narrowly winged petioles up to 1 cm long that clasp the stem. Leaf blades are 4 to 11 cm long, 1 to 3 cm wide, lanceolate to obovate with entire margins and a smooth waxy surface. Roots are relatively short and fine in water but become thicker and longer in soil. Stolons root at the nodes and can produce new plants if in

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This dissertation follows the style of Weed Technology.

contact with soil. Alligatorweed flower June to October, consisting of a simple terminal spike on an axillary peduncle 1 to 9 cm long somewhat like clover. They are polygamous, male and female with perfect flowers. Alligatorweed does not produce viable seed under field conditions (Center and Balciunas 1975; Julien 1995).

Alligatorweed is native of the South American coast from Venezuela to the Buenos Aires Province in Argentina (Vogt 1979) and has become widespread in tropical and warm temperate regions of the world (Parsons and Cuthbertson 2001). It is a serious problem of waterways in the southeastern United States, the irrigation districts of California, and is also a problem in Argentina, the Caribbean Islands, and parts of Africa, India, Malaysia, Southeast Asia, Indonesia, Australia, and New Zealand (Hockley 1974).

Alligatorweed was initially introduced to the southern United States from South America in the early 1880's as a contaminant of ship ballast. The earliest known specimen was collected near Charleston, South Carolina in 1885 followed by 1897 in Alabama and 1894 in Florida (Melvin 2003; Zeiger 1967). Alligatorweed's potential to overcome an area was recognized at the turn of the 20^{th} century, but was not taken seriously until the mid-1940's when application of 2,4-D eliminated its major competitor, water hyacinth (*Eichhornia crassipes*) (Kay and Hoyle 1999).

Alligatorweed is now found from the northern Virginia coast, south to Florida, and westward to Texas, and a few infestations reported in California (USDA, NRCS 2002). Spread inland has been primarily due to the movement of contaminated fish nursery stock. In 1981, increased infestations in the southern states were estimated only because of increases of the terrestrial form in Texas and Louisiana (Confrancesco 1988). Increased infestations may also be due to the mild winters since it will tolerate cold temperatures of $\geq$5 C (Shen et al. 2005). In the Unites States and China, frost may kill above ground parts but regrowth occurs in the spring (Coulson 1977). Penfound (1940) found that new shoots appearing in mid-March, were 40 cm long six weeks (wk) later and 63 cm long at 8 wk by measurements made in the Central United States. By 22 wk, plants had formed a mat that was 5 m^2.

Alligatorweed is a noxious weed for the states of Alabama, Arizona, Arkansas, California, South Carolina, and Texas, and is a prohibited aquatic plant in Florida (USDA, NRCS 2002). Alligatorweed is a serious weed on the west, south, and east coast of the United States and a problem in lowland rice in Taiwan and the United States (Holm et al. 1997). It is a major weed of irrigation systems in the U.S. and in transplanted rice. Alligatorweed has been recognized as an invasive and troublesome weed in rice in 23 provinces in China and responsible for yield losses up to 45% and $75 million economic loss in regions south of the Yellow River (Lu et al. 2002). Research on alligatorweed control has been mainly conducted with the aquatic form in water or irrigation canals. Limited research data are available for alligatorweed control in rice and control methods are needed in Texas and Louisiana.

Alligatorweed possess varing levels of resistance to all aquatic herbicides currently available (Parsons and Cuthbertson 2001). Multiple applications of 2,4-D kill emergent stems but have no effect on submerged stems. Fenoxyprop applied twice annually during early to mid-summer and late autumn reduced emergent stems to the water level, however, submerged stems were unaffected. Regrowth from treated areas was rapid (Julien and Broadbent 1980). In North Carolina, glyphosate effectively controlled aquatic alligatorweed, but did not control the terrestrial form. Imazapyr effectively controlled terrestrial alligatorweed in North Carolina (Langland 1986). In Louisiana, glyphosate applied mid-summer to late fall controlled alligatorweed >90% in dry ditches for up to 300 days after treatment (DAT). Spring applications to young, new growth were the least effective. Glyphosate applied to aquatic areas burned down alligatorweed to the water level; however, regrowth occurred by 45 DAT (Sandberg and Burkhalter 1983).

In rice, alligatorweed has become one of the ten most troublesome weeds in Florida, Louisiana, and Texas (Webster 2000; 2004). Effective control but not eradication, has been obtained with such herbicides as bentazon, bifenox, dicamba, fenoprop, pendimethalin, propanil, and triclopyr without serious damage to the crop (Julien and Broadbent 1980). Bispyribac-sodium has provided at least 85% control of small alligatorweed all season when applied early postemergence (EPOST) or late postemergence (LPOST) alone or in combination with thiobencarb, bensulfuron, or halosulfuron. Applications post flood to larger alligatorweed resulted in inadequate control (Braverman and Jordan 1996; Carey et al. 2000; Webster et al. 2003). Propanil alone or tank mixed with thiobencarb provides <60% control. Carfentrazone-ethyl plus clomazone applied at pegging in water seeded rice provided 90 to 94% control of alligatorweed 21 DAT. Delaying application to 7 days after the flood was established provided 25 to 60% control (Webster et al. 1999). Mid-September to early October application of glyphosate and picloram during the fallow year provided alligatorweed control greater than triclopyr, dicamba, and 2,4-D when evaluated monthly through the growing season in Louisiana when conservation tillage practices were used (Burns and Williams 2006). Mid-October or later applications did not provide adequate control.

Application timing of post emergent herbicides for adequate alligatorweed control is crucial as well as residual herbicide control. Imazethapyr applied EPOST to imidazolinone-resistant drill seeded rice provided at least 85% control of alligatorweed when followed by (fb) bensulfuron, triclopyr, bispyribac-sodium, and propanil + molinate 21 DAT (Pellerin et al. 2004). When imazethapyr was fb imazethapyr or carfentrazone-ethyl, control was inadequate. By 35 DAT, control was <69% for all treatments. In water seeded imidazolinone-resistant rice systems, alligatorweed control was inadequate with imazethapyr EPOST fb imazethapyr LPOST at 35 DAT (Pellerin et al. 2003). Control >85% was achieved when LPOST applications of imazethapyr was mixed with bensulfuron, carfentrazone, triclopyr, bispyribac-sodium, or propanil + molinate. LPOST treatments without EPOST application of imazethapyr provided inadequate control.

Penoxsulam (Grasp SC) is a new postemergence broad-spectrum herbicide developed by Dow AgroSciences for use in rice. It is a member of the triazolopyrimidine sulfonamide family of herbicides that inhibit the acetolactate synthase (ALS) enzyme of susceptible species in branched-chain amino acid synthesis. Penoxsulam received a reduced risk pesticide status as well as a Section 3 registration from the EPA in October 2004 for Arkansas, Florida, Mississippi, Missouri, Louisiana, and Texas (Anonymous

2004). Research data indicated that penoxsulam controls many important rice weeds such as *Echinochloa* species, northern jointvetch (*Aeschynomene virginica*), alligatorweed (*Alternanthera philoxeroides*), Texasweed/Mexicanweed (*Caperonia* spp.), annual sedge (*Cyperus* spp.), ducksalad (*Heteranthera limosa*), smartweed (*Polygonum* spp.), hemp sesbania (*Sesbania exaltata*) and many other broadleaf weeds (Richburg et al. 2005; Strahan 2004). Penoxsulam also controls propanil, quinclorac and ACCase resistant *Echinochloa* spp. Previous research indicated penoxsulam added broadleaf weed control to clomazone and imazethapyr in imidazolinone-tolerant rice where broadleaf weeds have become a problem in these systems (Lassiter et al. 2005; Meins et al. 2005).

Limited data are available on the control of alligatorweed with penoxsulam in rice production and results are variable between year and location. Studies conducted in Louisiana in 2003, (Webster et al. 2003), achieved 86% control of alligatorweed with penoxsulam EPOST 18 DAT, however, by 38 DAT control declined to 65%. Control in 2006 using penoxsulam applied at 0.035 g ai/ha EPOST, mid-postemergence (MPOST), or LPOST, was >88% when evaluated 29 days after LPOST (Webster et al. 2006). In Texas, O'Barr et al. (2004) reported >80% control from penoxsulam at a rate of 0.030 kg ai/ha EPOST.

Chemical control of alligatorweed has been investigated in both aquatic and terrestrial settings using aquatic and contact herbicides with little success. Due to the large underground network of rhizomes in the terrestrial form, regrowth occurs soon after herbicide application (Julien and Broadbent 1980). Imazapyr, an acetolactate synthase

(ALS) inhibitor, provided greater translocation to roots and long term control without regrowth but glyphosate caused desiccation of alligatorweed foliage but translocation was limited to roots (Tucker et al. 1994). These results are similar to Bowmer et al. (1993) who reported that only 7% of applied glyphosate reached underground organs of alligatorweed. Translocation of chlorimuron and imazaquin, both ALS inhibiting herbicides, was $\leq$1% to roots of pitted morningglory (*Ipomoea lacunosa* L.) (Shaw and Wesley 1993), however, 11% of imazethapyr was transported to roots of pitted morningglory (Kent et al. 1991). Understanding herbicide translocation can be exacerbated in perennial species. Herbicide movement could be affected by changes in relative sink strength of roots and shoots during establishment and growth of perennials. For instance, translocation of 2, 4-D in field bindweed (*Convolvulus arvensis*) was found to be different between seedling and vegetatively-propagated plants, with a more acropetal shift in herbicide accumulation with increasing age (Agbakoba and Goodin 1969). Limited translocation of herbicide to the roots of perennial species like alligatorweed would limit control.

New herbicide combinations must be tested for antagonism due to the variability between herbicides within a family and between weed species. Herbicide combinations may reduce weed control or injure the crop. Single applications of herbicide combinations for both grass and broadleaf weed control would reduce production cost compared to sequential applications (Ickeringill 1995). Antagonism has been observed between various graminicides mixed with broadleaf herbicides (Holshouser and Coble 1990; Vidrine et al. 1995). Efficacy of fenoxaprop was reduced when mixed with bentazon and triclopyr on grasses as well as when mixed with propanil and halosulfuron on barnyardgrass (*Echinochloa crus-galli*), but not on broadleaf signalgrass (*Brachiara platyphylla*) or Amazon sprangletop (*Leptochloa panicoides*) (Buehring et al. 2006; Jordan 1995; Stauber et al. 1991). Zhang et al. (2005a) reported no antagonistic effect observed from fenoxaprop mixed with propanil + molinate or bentazon on barnyardgrass. However, triclopyr, carfentrazone and halosulfuron were less compatible. Cyhalofop, a newly registered graminicide, displayed antagonism with three broadleaf herbicides, triclopyr, propanil, and halosulfuron on both propanil-resistant and susceptible barnyardgrass and broadleaf signalgrass (Scherder et al. 2005).

Reductions in efficacy when graminicides are mixed with ALS or photosystem II (PS II) herbicides have been partially explained by reductions in herbicide absorption and translocation. Propanil reduced the translocation of cyhalofop out of the treated leaf in barnyardgrass when combined and when propanil was applied 1 day before cyhalofop (Scherder et al. 2005). This may be due to the leaf burn and loss of membrane integrity. Propanil is a broad spectrum herbicide used in rice that inhibits the Hill reaction at PS II causing chlorosis within a few days (Senseman 2007). Bentazon, similar to propanil, is known to reduce sucrose production and translocation by inhibition of electron transport in PS II (Fuerst and Norman 1991). Penoxsulam, a phloem-mobile herbicide, may be inhibited when translocation and sucrose production is also inhibited by propanil (Devine et al. 1990). Bentazon decreased absorption and translocation of imazethapyr in “Olathe” pinto bean (*Phaseolus vulgaris*), common ragweed (*Ambrosia artemisiifolia*) and redroot pigweed (*Amaranthus retroflexus* L.) (Bauer et al. 1995a; Bauer et al.

1995b; Hager et al. 1999). Pyribenzoxim translocation was reduced when applied to barnyardgrass in combination with propanil (Koo et al. 2000). Through the development of penoxsulam, tank mixes with various herbicides such as propanil have been evaluated for efficacy using different modes of action. Antagonism has not been identified except for alligatorweed control. O'Barr et al. (2004) reported possible antagonism between penoxsulam and propanil on alligatorweed. Possible antagonism between propanil and penoxsulam may be a result of reduced translocation from reduced sucrose production from propanil inhibiting predominately phloem-mobile herbicides.

Antagonism has been successfully alleviated by increasing application rates of the antagonized herbicide or by applying the herbicides sequentially separated by a few days (Culpepper et al. 1998; Palmer et al. 2000). The antagonistic affect of bromoxynil on quizalofop for large crabgrass (*Digitaria sanguinalis*) and yellow foxtail (*Setaria glauca*) control was minimized when bromoxynil was applied 6 d prior or 3 d after quizalofop (Culpepper et al. 1999). Corkern et al. (1998) reported bromoxynil antagonism was reduced when applied 3 d prior or 7 d after the fluazifop application. Triclopyr and halosulfuron antagonism to cyhalofop was reduced when applied at least 3 d before or after cyhalofop on propanil-resistant and susceptible barnyardgrass and broadleaf signalgrass, however propanil was antagonistic when tank mixed with cyhalofop (Scherder et al. 2005). Sequential application increased control. Propanil treatment during the period of 1 d before through 5 d after pyribenzoxim application was antagonistic and showed greater antagonism the shorter the interval between applications (Koo et al. 2000). Increasing the rate of the antagonized herbicide had little effect on the amount of antagonism without reaching control equal to the single application (Barnes and Oliver 2004; Culpepper et al. 1999; Koo et al. 2000).

Environmental conditions at application may alter the efficacy of herbicides by changing absorption and translocation as well as the level of weed control (Coupland 1983; Kudsk et al. 1990). Air temperature and soil moisture can cause plant stress influencing leaf cuticular composition and foliar penetration, therefore, decreasing the activity of herbicides (Hsaio 1973; Hull et al. 1975). Foliar application of imazamethabenz controlled wild oat greater at 16/10 C (day/night) than at 11/7 or 26/16 C compared to blackgrass (*Alopecurus myosuroides*) with greater control at 26/16 C (Shaner and O'Connor 1991). Glyphosate applications to quackgrass (*Elymus repens*) provided greater control as temperature, humidity, and light increased (Coupland 1983). Geier et al. (1999) reported that plant dry weight reduction was greater at 10/5 C than at 21/7 C for cheat (*Bromus secalinus*), however, just the opposite for wheat (*Triticum aestivum*) at 7% soil moisture. As soil moisture increased, percent dry weight reduction increased without differences between temperatures. Absorption and translocation can also be deterred by temperature and soil moisture and can vary between weed species and/or herbicides. Translocation of pyrithiobac in velvetleaf (*Abutilon theophrasti*), metribuzin in jointed goatgrass (*Aegilops cylindrical*), downy brome (*Bromus tectorum*), and wheat, and atrazine in common bean and redroot pigweed was greater at higher temperatures (30 to 25 C) and soil moistures (field capacity and ¾ field capacity) than lower temperatures and soil moisture (Al-Khatib et al. 1992; Buman et al. 1992; Harrison et al. 1996). In contrast, wheat and wild oat absorbed and translocated more sulfosulfuron at lower temperatures, 15/13 C day/night temperature, and downy brome was unaffected (Olson et al. 1999).

Since penoxsulam is an ALS inhibitor, potential rice injury was a concern. In the past, ALS inhibiting herbicides have caused significant injury to rice plants. Bispyribac-sodium was reported to have caused 10 to 16% root injury when applied EPOST and LPOST to rice. When mixed with another ALS inhibiting herbicide, bensulfuron, injury was 16% (Braverman and Jordan 1996). Scasta et al. (2004) also provided evidence that bispyribac-sodium, especially at pre-flood, injured rice up to 30% and injury increased with rate. Root length was diminished with a pre-flood application evaluated 14 DAT. Root injury has been identified with penoxsulam when applied to rice at the 2- to 3-leaf or pre-flood stage. Both, 31 g ai/ha and 62 g ai/ha reduced root growth of ‘Cocodrie’ as much as 35% (Meins et al. 2005).

Rice tolerance to herbicides may be dependent on cultivar and timing of application. Triclopyr caused 25% injury to long grain ‘Lemont’ rice but only 16 and 15% injury to ‘Mars’ and ‘Tebonnet’ rice cultivars when averaged over timings. Bromoxynil had the opposite effect on the same cultivars with Lemont as most tolerant (Pantone and Baker, 1992). ‘Jodon’ cultivar was injured 13% when data were pooled over triclopyr rates, growth stages, and years; however, ‘Bengal’, ‘Cypress’, and ‘Kaybonnet’ all had $< 8\%$ injury. Increasing the rate of triclopyr from 420 to 840 g ai/ha, applied at the 4-leaf rice stage caused 22% injury compared to 2% injury when applied at the panicle initiation stage. Triclopyr applied pre-flood at 840 g ai/ha reduced yield compared to application at panicle initiation independent of cultivar (Jordan et al. 1998). Bispyribac-sodium caused greater injury to Bengal than Cocodrie. Root fresh weight for Bengal was reduced 60 to 77% compared to the non-treated check; however, Cocodrie was only reduced 15 to 27% at 2 and 3 weeks after treatment (WAT) when applied at 20 (1x) and 40 (2x) g ai/ha to 1- to 2-leaf rice. Data for bispyribac-sodium applied at the 2- to 3-leaf rice stage resulted in differences similar to the 1- to 2-leaf stage (Zhang and Webster, 2002). Zhang et al. (2005b) concluded that 'Earl' cultivar was less tolerant to bispyribac-sodium than Bengal, Cocodrie, Cypress, 'Wells', 'CL-161', and 'CL-141' when injury, plant height, and yield was measured. Penoxsulam caused 58 and 52% root pruning to Wells in Arkansas 2 WAT when applied at 35 g ai/ha (1x) and 70 g ai/ha (2x), respectively, at the 4-to 5-leaf rice stage (Ellis et al., 2005). Applications made at 1- to 2-leaf and 1 week post-flood at the same rates of penoxsulam reduced root growth 38 to 41% and 44 to 45%, respectively. Penoxsulam applied at the 4- to 5-leaf rice stage at 0.032 and 0.064 g ai/ha injured roots of Cocodrie 65 and 77% and Bengal 53 and 63%, respectively, at 2 WAT. 'XL8' cultivar was least affected by penoxsulam resulting in 4 and 7% root growth inhibition at the two rates, respectively. By 3 WAT, root growth recovered and was equal to the root growth of the non-treated check for all varieties with no effect on yield (Ellis et al. 2005).

Flood timing influences weed control (Richard and Street 1984) and may affect the tolerance of rice cultivars to herbicides. Fenoxaprop applied at the 1 tiller rice stage of 'Lebonnet' cultivar resulted in higher phytotoxicity the earlier the flood was established (Thomas 1984). Yield of 'Newbonnet' and 'Starbonnet' cultivars were reduced as flood-timing interval after application of fenoxaprop was shortened (Snipes et al. 1987).

Literature is limited on the tolerance of rice cultivars to penoxsulam influenced by flood timing and root stunting or yield. The penoxsulam revised label (November 2004) indicated to delay flood establishment until 3 DAT (Anonymous, 2004). Root stunting was still observed beyond timing at 3 DAT and it is not known whether root stunting reduce yield.

Alligatorweed is a noxious weed in Texas and has migrated from waterways to the ditches and canals that supply irrigation water to the rice fields. As a perennial, alligatorweed produces a massive underground rhizome system making herbicide control difficult. Control/suppression may be achieved through the growing season however regrowth is rapid within days. Penoxsulam is a new herbicide for weed control in rice and possibly a substitute for propanil as propanil resistant weeds emerge. Obtaining a better understanding of penoxsulam behavior and environmental factors favoring its efficacy is needed. The objectives of this research was to: 1) evaluate the effects of select rice herbicides on alligatorweed control, 2) determine the absorption and translocation efficiency of penoxsulam and the effect of propanil on penoxsulam in alligatorweed 3) access application timing and air temperature effects on penoxsulam efficacy to avoid antagonism with propanil and, 4) evaluate the effects of flood timing and rice cultivars on rice root stunting and plant foliar injury from penoxsulam applications.

CHAPTER II

INFLUENCE OF FLOOD INTERVAL AND CULTIVAR ON RICE TOLERANCE TO PENOXSULAM*

INTRODUCTION

Penoxsulam is a new postemergence herbicide developed for use in rice. It is a member of the triazolopyrimidine sulfonamide family of herbicides that inhibit the acetolactate synthase (ALS) enzyme (#4.1.3.18) in branched-chain amino acid synthesis of susceptible weed species. Penoxsulam controls many important weeds in rice including *Echinochloa* spp., northern jointvetch (*Aeschynomene virginica* L.), alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.], Texasweed/Mexicanweed (*Caperonia* spp.), annual sedge (*Cyperus* spp.), ducksalad [*Heteranthera limosa* (Sw.) Willd], smartweed (Polygonum spp.), and hemp sesbania [*Sesbania herbacea* (P. Mill)] (Richburg et al. 2005; Strahan 2004).

Injury to rice from ALS-inhibiting herbicides has been observed (Braverman and Jordan 1996). Bispyribac-sodium caused 10 to 16% root injury when applied early postemergence and late postemergence to rice. Scasta et al. (2004) also provided evidence that bispyribac-sodium, especially when applied pre-flood, injured rice up to 30%, and injury increased with rate. Root length was diminished with a pre-flood application evaluated 14 DAT. Root injury has been observed with penoxsulam when

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applied to rice at the two to three-leaf stage or at pre-flood. Penoxsulam at 31 and 62 g/ha reduced root growth of Cocodrie up to 35% (Meins et al. 2005).

Rice tolerance to herbicides may be dependent on cultivar and application timing. Triclopyr caused 25% foliar injury to Lemont rice but only 16 and 15% injury to Mars and Tebonnet, respectively, when averaged over timings (Pantone and Baker 1992). Bromoxynil had the opposite effect on the same cultivars, with Lemont being the most tolerant. Jodon was injured 13% when data were pooled over triclopyr rates, growth stages, and years; however, Bengal, Cypress, and Kaybonnet were injured < 8% (Jordan et al. 1998). Bispyribac-sodium caused greater injury to Bengal than Cocodrie (Zhang and Webster 2002). Bengal root fresh weight was reduced 60 to 77% compared with nontreated. Cocodrie root fresh weight was only reduced 15 to 27% at 2 and 3 wk after treatment (WAT) when bispyribac-sodium was applied at 20 and 40 g/ha to rice in the one to two-leaf stage. Bispyribac-sodium applied to two to three-leaf rice resulted in similar differences (Zhang and Webster 2002). In other research, Earl was less tolerant to bispyribac-sodium than other cultivars when foliar injury, plant height, and yield were measured (Zhang et al. 2005b). Penoxsulam applied at 30 or 70 g/ha to one to two-leaf rice, four to five-leaf rice, and at 1 wk post-flood caused 38 and 41%, 58 and 52%, and 45 and 44% root stunting, respectively, to Wells evaluated at 2 weeks after flood (WAF) (Ellis et al. 2005). When applied to four to five-leaf rice, penoxsulam at 30 or 70 g/ha injured roots of Cocodrie 65 and 77% and Bengal 53 and 63%, respectively, at 2 WAT. Hybrib ‘XL8’ was least affected by penoxsulam resulting in <8% root growth inhibition at the two rates. By 3 WAT, root growth recovered and was equal to the non-treated control for all cultivars with no effect on yield (Ellis et al. 2005).

Flood timing influences weed control (Richard and Street 1984), and may affect the tolerance of rice cultivars to herbicides. Yield of Newbonnet and Starbonnet cultivars were reduced as flood-timing interval after application of fenoxaprop was shortened (Snipes et al. 1987).

Currently, no data exist on the tolerance of rice cultivars to penoxsulam as influenced by flood timing. Recommendations are to delay permanent flood establishment for 3 d after a penoxsulam application (Anonymous 2004). However, root stunting has been observed beyond this timing (R. B. Lassiter, personal communication). There has been no research to correlate root injury from penoxsulam or rice grain yield. The objective of this study was to determine the level of rice tolerance to penoxsulam as impacted by flood timing for several commonly-grown cultivars and to evaluate its effect on grain yield.

MATERIALS AND METHODS

Field studies were conducted in 2003 at two sites in Greenville, MS, on a producer's private farm in Humphrey, AR and in 2004 in Greenville, MS, Stoneville, MS, Humphrey and Newport, AR, and at Eagle Lake, TX to determine the level of rice tolerance to penoxsulam as impacted by flood timing for several commonly-grown cultivars. Soil classification and texture for each location are presented in Table 1. All locations are representative of rice producing areas in Mississippi, Arkansas, and Texas.

Table 1. Soil texture analysis and pH for Mississippi, Arkansas, and Texas experiment locations in 2003 and 2004.

Location	Soil classification	%Sand	%Silt	%Clay	pH
2003					
Greenville, MS	Mhoon silty clay loam (Fine-silty, mixed, nonacid, thermic, Typic Fluvaquents)	11	68	21	7.1
Greenville, MS	Mhoon silt loam (Fine-silty, mixed, nonacid, thermic, Typic Fluvaquents)	25	52	22	7.1
Humphrey, AR	Rilla silt loam (Fine silty, mixed, thermic, Typic Hapludalfs)	29	37	34	5.1
2004					
Greenville, MS	Sharkey clay (Very-fine, montmorillonitic, nonacid, thermic Vertic)	7.5	22	70	6.4
Stoneville, MS	Sharkey silty clay loam (Very-fine, montmorillonitic, nonacid, thermic Vertic)	11	46	42	7.3
Humphrey, AR	Rilla loam (Fine silty, mixed, thermic Typic Hapludalfs)	52	30	18	5.5
Newport, AR	Bosket fine sandy loam (Fine-loamy, mixed, thermic, Mollic Hapludalfs)	76	10	14	5.6
Eagle Lake, TX	Crowley fine sandy loam (Fine, smectitic, hyperthermic, Typic Albaqualfs)	59	29	12	5.3

Field preparation consisted of fall disking followed by precision leveling and field cultivation before planting.

Five cultivars, including one medium-grain cultivar (Bengal) and three long-grain cultivars (Cypress, Wells, and Cocodrie) were drill seeded at 78 kg/ha. The long-grain rice hybrid, ‘XP712’, was also included and seeded at 50 kg/ha. Planting dates ranged from April 7 to April 30 during the two-year study. Plot size was nine rows spaced 20 cm apart by 5.4 m long. Seeds were pretreated with the insecticide fipronil {5-amino-1-[2,6-dichloro-4-trifluoromethyl)phenyl]-4-(trifluoromethylsulfinyl)-1*H*-pyrazole-3-carbonitrile} for rice water weevil (*Lissorhoptrus oryzophilus*) control. Soil fertility management at each location was consistant with local cultural practices and state recommendations. Soil moisture was maintained by flush irrigation (briefly flooded and drained) to promote rice growth and herbicide incorporation.

The four herbicide treatments consisted of POST applications of quinclorac at 420 g ai/ha plus propanil at 4480 g ai/ha as the standard treatment, bispyribac-sodium at 30 g/ha, and penoxsulam at 30 and 60 g/ha. A crop oil concentrate[1] was added to penoxsulam at 2.5% v/v. A silicon-based surfactant[2] at 0.125% v/v was added to bispyribac-sodium. All treatments were applied to rice in the 4- to 5-leaf rice stage, with the permanent flood established 1, 7, or 14 days after treatment (DAT). Weed-free conditions were maintained by preemergence (PRE) application of clomazone to the entire study immediately after planting at recommended rates by soil characteristics for each site. All herbicide applications were made using a CO_2 or compressed air pressurized backpack sprayer and boom calibrated to deliver 94 L/ha. The site was separated into three areas by levees each representing a flood timing. Cultivars and herbicide treatments were randomized within each flood timing.

The study was designed as a split-split plot with four replications. The main plot was three flood timings of 1, 7, and 14 DAT of postemergence (POST) herbicide application. Sub-plots consisted of the five rice cultivars and herbicide treatments were sub-subplots.

Visual evaluation of rice foliar injury and root growth inhibition were estimated 1, 2, 3, and 4 WAT for each flood timing. Foliar rice injury was evaluated using a scale of 0 to 100% where 0 = no injury and 100 = complete rice death by comparing plant growth reduction to the standard treatment of quinclorac plus propanil. Root growth inhibition was evaluated by extracting one randomly selected plant for each plot (Zhang and Webster 2002). Plants were gently pulled to minimize root breakage and then washed to remove the soil from the root mass. Ratings were a measurement of percent root reduction based on root mass of the treated plants compared to quinclorac plus propanil-treated plant within each cultivar. This was repeated for each replication and cultivar within each flood timing. Rice grain was harvested using a small plot grain harvester[3] when grain moisture was approximately 20%. Final grain yield was adjusted to 12% moisture content.

All data were subjected to the Mixed Procedure (SAS 2002). Year, locations, replications (nested within year), and all interactions between these were considered random effects. This allowed inferences to be made about treatments and flood timings over a range of environments (Carmer et al. 1989). Herbicide treatments, flood timings, cultivars, and their interactions were considered fixed effects. Data were analyzed comparing flood timings, herbicide treatments and cultivars and any interactions between them. Type III statistics were used to test all possible effects of fixed effects along with Fisher's protected LSD to determine mean separation at the $P \leq 0.05$ level. Next, the flood timing that resulted in the most rice injury was then analyzed in order to reduce variation introduced from other flood timings. Proc mixed Procedure was used for testing herbicide treatments and cultivars and their interaction. Choosing to analyze one flood timing over other flood timings was determined due to the greater root growth inhibition (RGI) at that particular flood timing.

RESULTS AND DISCUSSION

A flood timing by cultivar interaction occurred for RGI, therefore, data were presented to reflect the interaction (Table 2). Herbicide treatments and all interaction containing herbicide treatments were not significant as well as the three-way interaction between cultivar, herbicide treatment, and flood timing.

At 1 week after flood establishment (WAF), RGI was similar at flood timings 1 (15 to 21%) and 7 (16 to 18%) DAT for cultivars Bengal, Cocodrie, Cypress, and Wells (Table 2). Cultivar XP712 exhibited lower RGI (<5%) at these flood timings. Root growth inhibition for each cultivar was similar at 1 and 7 DAT. Root growth inhibition persisted at 2 WAF following flood at 1 DAT from 15 to 19% for all cultivars except XP712 (0%). Bengal (19 vs 12%), Cypress (19 vs 13%), and Wells (16 vs 12%) had a higher RGI following flood 1 DAT compared to 7 DAT. Cocodrie exhibited similar RGI at flood 1 and 7 DAT, 15 and 13% respectively, taking longer to recover, and less

Table 2. Percent root growth inhibition[a] from herbicide treatments as influenced by flood timing of 1, 7 and 14 DAT for five rice cultivars evaluated at 1 and 2 weeks after flood (WAF) establishment[b].

			Flood timing (DAT)		
Evaluation date	Rice cultivar	Grain size	1	7	14
			%		
1 WAF	Bengal	Medium	21 Aa[c]	17 Aa	11 Ab
	Cocodrie	Long	16 Aa	17 Aa	8 Ab
	Cypress	Long	19 Aa	18 Aa	9 Ab
	Wells	Long	15 Aa	16 Aa	10 Ab
	XP712	Long	4 Ba	0 Ba	0 Ba
2 WAF	Bengal	Medium	19 Aa	12 Ab	3 Ac
	Cocodrie	Long	15 Aa	13 Aa	2 Ab
	Cypress	Long	19 Aa	13 Ab	3 Ac
	Wells	Long	16 Aa	12 Ab	3 Ac
	XP712	Long	0 Ba	0 Ba	0 Ba

[a] Root growth inhibition: % reduction in root mass as compared to propanil + quinclorac.

[b] Abbreviations: DAT, d after treatment; WAF, weeks after flood establishment.

[c] Means followed by the same uppercase letter within columns for each flood timing and means followed by the same lowercase letter within each cultivar are not significantly different using Fisher's protected LSD at $p \leq 0.05$.

when flooded 14 DAT (2%). Cultivars Bengal, Cocodrie, Cypress, and Wells exhibited lowest RGI at 14 DAT (2 to 3%).

These data indicate that delaying flood establishment to 14 DAT would reduce RGI by herbicides evaluated. In addition, cultivar XP712 exhibited excellent tolerance to all herbicides with no greater than 4% RGI at any timing. The penoxsulam label indicates that moist soil conditions enhance weed control allowing more herbicide to be available for uptake from the soil solution (Anonymous 2004). Beginning at the two to three-leaf stage, rice begins to develop secondary roots that actively undergo cell division (Dunand 1999). ALS inhibitors delay the cell division component of growth (Ray 1982). This may have led to RGI at early flood timings. Additionally, source leaves of susceptible plants treated with ALS-inhibiting herbicides have a decreased supply of photosynthates supporting the growth of secondary roots (Devine et al. 1990). Flooding soon after herbicide application increases herbicide availability for root uptake and increases injury potential.

As a worst-case scenario, evaluation of RGI from penoxsulam and bispyribac-sodium for five rice cultivars was analyzed again using only the earliest possible flood timing, 1 DAT (Table 3). The interaction between cultivar and herbicide treatment was significant when flood timing 1 DAT was analyzed separately from the other flood timings; therefore, data were presented to reflect this interaction (Table 3). At 1 WAT, RGI was greater from bispyribac-sodium for Bengal (25 vs 15) and Cypress (23 vs 14%) compared to penoxsulam at 30 g/ha, but similar when compared to penoxsulam at 60 g/ha (21 to 25%). Differences among treatments were similar for Wells and Cocodrie

Table 3. Percent root growth inhibition[a] at flood timing 1 DAT[b] as influenced by herbicide treatment for five rice cultivars.

Herbicide treatment		Rate	Root growth inhibition				
			Bengal	Wells	Cocodrie	Cypress	XP712
		g ai/ha			%		
1 WAT[b]	bispyribac-sodium	30	25 Aa[c]	18 Aa	16 Aa	23 Aa	4 Ab
	Penoxsulam	30	15 Ba	14 Aa	13 Aa	14 Ba	3 Ab
	Penoxsulam	60	22 ABa	17 Aa	18 Aa	21 ABa	4 Ab
2 WAT	bispyribac-sodium	30	20 Aa	16 Aa	10 Bb	22 Aa	2 Ac
	Penoxsulam	30	16 Aa	13 Aa	16 ABa	18 Aa	0 Ab
	Penoxsulam	60	22 Aa	21 Aa	19 Aa	18 Aa	2 Ab
3 WAT	bispyribac-sodium	30	15 Aa	11 Aa	12 ABa	10 Ba	0 Ab
	Penoxsulam	30	10 Aa	11 Aa	11 Ba	10 Ba	0 Ab
	Penoxsulam	60	14 Aa	17 Aa	18 Aa	19 Aa	0 Ab

[a] Root growth inhibition, foliar injury: % reduction in root mass and above ground rice plant growth compared to propanil + quinclorac.

[b] Abbreviations: DAT, d after treatment; WAT, weeks after treatment.

[c] Means followed by the same uppercase letter within columns for each WAT and means followed by the same lowercase letter within each herbicide treatment for each WAT are not significantly different using Fisher's protected LSD at $p \leq 0.05$.

with RGI ranging from 13 to 18%. Root growth inhibition was similar among cultivars from each treatment except XP712, which exhibited <5% RGI (Table 3).

By 2 WAT, all cultivars exhibited similar RGI among herbicide treatments (13 to 22%) with the exception of Cocodrie showing greater RGI from penoxsulam at 60 g/ha compared to bispyribac-sodium (19 vs 10%) (Table 3). Cocodrie began to recover from bispyribac-sodium with less RGI compared to other cultivars except cultivar XP712 at 2 WAT. XP712 exhibited <3% RGI, lower than the other cultivars. At 3 WAT, RGI for Cocodrie treated with penoxsulam at 30 g/ha was similar to bispyribac-sodium (11 vs 12%) and less than penoxsulam at 60 g/ha (11 vs 18%) (Table 3). Cypress exhibited less RGI from bispyribac-sodium (10%) and penoxsulam at 30 g/ha (10%) compared to penoxsulam at 60 g/ha (19%). Bengal and Wells showed no differences among herbicide treatments with RGI ranging from 10 to 17%. Root growth inhibition was similar among cultivars from each treatment except XP712 with <5% RGI.

Herbicide treatment by cultivar interaction was significant for foliar injury. Flood timing or any interaction including flood timing for plant foliar injury was not significant, therefore, data were presented to reflect this interaction (Table 4). Injury symptoms observed were slight stunting of rice growth with very slight chlorosis. At 1 WAT, bispyribac-sodium showed greater foliar injury, 9 to 14%, compared with penoxsulam for all cultivars except XP712, which exhibited <6% injury. Bengal foliar injury (14%) was greater form bispyribac-sodium compared to other cultivars (5 to 11%). At 2 WAT, Bengal foliar injury from penoxsulam at 60 g/ha and bispyribac-sodium was similar (15 and 12%) and greater compared to penoxsulam at 30 g/ha (8%).

Table 4. Percent foliar injury averaged across flood timings as influenced by herbicide treatment for five rice cultivars.

		Foliar injury				
Herbicide treatment	Rate	Bengal	Wells	Cocodrie	Cypress	XP712
				%		
1 WAT[a]						
Bispyribac-sodium	30	14 Aa[b]	9 Ab	10 Ab	11 Ab	5 Ac
Penoxsulam	30	4 Ca	3 Ba	2 Ca	3 Ba	0 Aa
Penoxsulam	60	6 Ba	3 Ba	4 Ba	5 Ba	0 Aa
2 WAT						
Bispyribac-sodium	30	15 Aa	10 Ab	7 Ab	8 Ab	3 Ac
Penoxsulam	30	8 Ba	6 Aa	5 Aa	6 Aa	0 Aa
Penoxsulam	60	12 Aa	7 Ab	7 Ab	7 Ab	0 Ac
3 WAT						
Bispyribac-sodium	30	9 Aa	8 Aa	6 Aa	6 Aa	0 Aa
Penoxsulam	30	8 Aa	7 Aa	6 Aa	6 Aa	0 Aa
Penoxsulam	60	11 Aa	11 Aa	10 Aa	8 Aa	0 Aa

[a] Abbreviations: WAT, weeks after treatment.

[b] Means followed by the same uppercase letter within columns for each WAT and means followed by the same lowercase letter within each herbicide treatment for each WAT are not significantly different using Fisher's protected LSD at $p \leq 0.05$.

All other cultivars showed less foliar injury (0 to 10%) compared to Bengal with bispyribac-sodium and penoxsulam at 60 g/ha. By 3 WAT, there were no differences among herbicide treatments or cultivars. Cultivar XP712 exhibited less than 6% foliar injury at all ratings (Table 4).

Rice grain yield is important to determine if initial root injury or foliar injury had a long-term adverse effect on grain development and provides a better understanding of the plant's ability to recover. Flood timing, herbicide treatment, and flood timing by herbicide treatment interaction for each cultivar was not significant for rice yield. Yield for XP712 ranged from 10683 to 11306 kg/ha (data not shown) and Cocodrie, Cypress, Bengal, and Wells yield ranged from 8010 to 8991 kg/ha. All treatments were similar to the standard treatment.

These data indicate that flood timing affected RGI for rice cultivars with penoxsulam and bispyribac-sodium. Flooding 1 or 7 DAT consistently resulted in greater RGI than when flood was delayed to 14 DAT. The earlier the flood timing, the longer RGI persisted. By 4 WAT, rice plants recovered from initial herbicide injury. For all cultivars, grain yield was not adversely affected by initial injury from herbicide treatments. For the worse-case scenario at flood 1 DAT, when more herbicide was available for plant uptake, RGI was greater with bispyribac-sodium for Bengal and Cypress when compared to penoxsulam at 30 g/ha. Differences between these treatments were not evident 1 week later. Penoxsulam at 30 and 60 g/ha and bispyribac-sodium initially inhibited root growth, however, rice plants recovered resulting in no yield reduction compared to the standard treatment. These results indicate that early flood timing resulted in prolonged RGI for Bengal, Wells, Cocodrie, and Cypress from penoxsulam, but grain yield was not adversely affected. XP712 was most tolerant to the herbicide treatments and flood timings with < 5% RGI and foliar injury. Hybrids have inherently higher yield potential such as XP712 providing greater yield than other cultivars evaluated.

CHAPTER III

ALLIGATORWEED CONTROL IN RICE WITH PENOXSULAM

INTRODUCTION

Alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.] is found on the coast of northern Virginia, south to Florida, westward to Texas, and California (USDA 2002) as well as in lowland rice in Taiwan and the United States (Holm et al. 1997). Alligatorweed has been recognized as an invasive and troublesome weed in rice in 23 provinces in China and is responsible for a 45% yield loss or loss of around $75 million in regions south of the Yellow River (Lu et al. 2002). Alligatorweed can survive the mild winter of the southern U.S. by tolerating cold temperatures of $\geq$5 C (Shen et al. 2005). Frost may kill above ground parts but regrowth occurs in the spring (Coulson 1977).

Alligatorweed is a member of the amaranthaceae family. Reproduction is entirely vegetative with two viable axillary buds capable of growth at all stem nodes. Alligatorweed does not produce viable seed under field conditions (Center and Balciunas 1975; Julien 1995). On land, cultivation may drag pieces of stolons to clean areas and with whole or partial soil contact, new plants are produced that increase infestation (Parsons and Cuthbertson 2001). Plant biomass can double in the field in approximately 50 days during the summer (Brown and Spencer 1973).

Alligatorweed has become one of the ten most troublesome weeds in Florida, Louisiana, and Texas rice since 2000 (Webster 2000, 2004). Effective control but not eradication, has been obtained with such herbicides as bentazon, bifenox, dicamba, fenoprop, pendimethalin, propanil, and triclopyr without serious damage to the crop (Julien and Broadbent 1980). In Louisiana, glyphosate and picloram applications mid-summer to late fall controlled alligatorweed >90% for up to 300 days after treatment (DAT) greater than triclopyr, dicamba, and 2,4-D. Spring applications to young, new growth were the least effective (Burns and Williams 2006). Mid-October or later applications did not provide adequate control. Bispyribac-sodium provided at least 85% alligatorweed control all season when applied early postemergence (EPOST) or late postemergence (LPOST) alone or in combination with thiobencarb, bensulfuron, or halosulfuron when alligatorweed is 7 to 14 cm tall. Applications post flood when alligatorweed is 15 to 25 cm tall results with inadequate control from many herbicides (Braverman and Jordan 1996; Carey et al. 2000; Webster et al. 1999; Webster et al. 2003). Propanil alone or tank mixed with thiobencarb provides <60% control.

Timing of herbicide application and obtaining residual control from herbicides is important. Imazethapyr applied EPOST to imidazolinone-resistant drill seeded rice provided at least 85% control of alligatorweed when followed by (fb) bensulfuron, triclopyr, bispyribac-sodium, or propanil + molinate 21 DAT (Pellerin et al. 2004). When imazethapyr was fb imazethapyr or carfentrazone-ethyl, control was inadequate. By 35 DAT control was <69% for all treatments mentioned. In water seeded imidazolinone-resistant rice systems, alligatorweed control was inadequate with imazethapyr EPOST fb imazethapyr LPOST at 35 DAT (Pellerin et al. 2003). Control greater than 85% was achieved when LPOST applications of imazethapyr was mixed with bensulfuron, carfentrazone, triclopyr, bispyribac-sodium, or propanil + molinate. LPOST treatments without an EPOST application of imazethapyr provided inadequate control.

Penoxsulam (Grasp SC) is a new postemergence broad-spectrum herbicide developed by Dow AgroSciences for use in rice. It is a member of the triazolopyrimidine sulfonamide family of herbicides that inhibit the acetolactate synthase (ALS) enzyme of susceptible species used in branched-chain amino acid synthesis. Penoxsulam received a Reduced Risk Pesticide status as well as a Section 3 registration from the EPA in October 2004 for Arkansas, Florida, Mississippi, Missouri, Louisiana, and Texas (Anonymous 2004). Research data indicated that penoxsulam controls many important weeds in rice such as *Echinochloa* propanil, quinclorac and ACCase resistant species as well as alligatorweed (Richburg et al. 2005; Strahan 2004).
Additionally, previous research indicated penoxsulam added broadleaf weed control to clomazone and imazethapyr based programs where broadleaf weeds have become a problem in these systems (Lassiter et al. 2005; Meins et al. 2005).

There is limited research published on the control of alligatorweed with penoxsulam in rice production and these results are variable between year and location. In Louisiana in 2003, 86% control of alligatorweed was achieved with penoxsulam EPOST 18 DAT, however, by 38 DAT control declined to 65% (Webster et al. 2003). Control in 2006 using penoxsulam applied at 3 timings, EPOST, mid-postemergence (MPOST), or LPOST, was >88% when evaluated 29 days after LPOST (Webster et al. 2003, 2006). In Texas, O’Barr et al. (2004) reported >80% control from penoxsulam at 0.030 kg ai/ha

EPOST. The objective of this study was to evaluate penoxsulam alone and in various tank mixes with commonly used rice herbicides at different timings in drill-seeded rice for effective alligatorweed control and optimal rice yield in Texas.

MATERIALS AND METHODS

Field studies were conducted in 2004 and 2005 at four locations and in 2006 at two locations in the rice producing region of Texas with substantial alligatorweed populations. Study sites included commercial production fields near Eagle Lake, Garwood, Ganado and Lissie, TX. Soil classification and texture are presented in Table 5. Field preparation consisted of fall disking followed by precision leveling and field cultivation before planting. Plantings dates ranged from March 22 to April 5 during the three year study. Plot size was nine rows spaced 20 cm apart by 5.4 m long. Seeds were pretreated with the insecticide fipronil {5-amino-1-[2,6-dichloro-4-trifluoromethyl)phenyl]-4-(trifluoromethylsulfinyl)-1*H*-pyrazole-3-carbonitrile} for rice water weevil control. Soil fertility management at each location was consistent with local cultural practices and state recommendations. Soil moisture was maintained by flush irrigation (briefly flooded and drained) to promote rice growth and herbicide activation.

A randomized complete block design was utilized to analyze the data with four replications. The herbicide treatments consisted of penoxsulam at 30 or 35 g ai/ha alone

Table 5. Soil texture analysis and pH for Texas experiment locations in 2004, 2005, and 2006.

Location	Soil classification	% Sand	%Silt	% Clay	pH
Eagle Lake, TX	Crowley fine sandy loam (fine, smectitic, hyperthermic Typic Albaqualfs)	59	29	12	5.3
Ganado, TX	Edna fine sandy loam (fine, montmorillonitic, thermic, Vertic Hapludalfs)	55	33	12	6.1
Garwood, TX	Nado-Cieno fine sandy loam (siliceous, active, hyperthermic Albaquic Hapludalfs)	57	25	18	5.9
Lissie, TX	Crowley fine sandy loam (fine, smectitic, hyperthermic Typic Albaqualfs)	56	25	19	6.7

and in combination with propanil at 3362 g/ha or triclopyr at 210 g/ha as well as propanil plus triclopyr applied either at the 3-leaf rice stage (EPOST) or the 4- to 5-leaf rice stage (LPOST). Alligatorweed stolens were 5 to 13 cm long at EPOST and 10 to 20 cm long at LPOST applications. Additional LPOST applications included bispyribac-sodium at 28 g/ha alone and in combination with propanil or triclopyr, bensulfuron at 70 g/ha alone or with propanil, prosulfuron at 20 g/ha, quinclorac plus propanil plus halosulfuron at 336, 3362, and 33 g/ha, respectively, and penoxsulam plus halosulfuron. Treatments of bispyribac-sodium with two surfactants, a silicon-based surfactant[4] at 0.125 % v/v plus urea ammonium nitrate (UAN) and Dyne-A-Pak[5] at 1% v/v were added in 2006. A crop oil concentrate[6] at 2% v/v was included with all treatments except with bispyribac-sodium which included a silicon-based surfactant at 0.125% v/v. Grass control was maintained by using clomazone applied preemergence (PRE) to the entire study immediately after planting at 390 g/ha, recommended rate as determined by soil characteristics at each study location. All herbicide applications were made using a CO_2 pressurized backpack sprayer with four flat-fan nozzle boom calibrated to deliver 140 L/ha.

Visual evaluation of alligatorweed control was estimated 14 and 42 DAT using a scale of 0 to 100% where 0 = no control and 100 = complete weed death by comparing to the untreated plot. Rice grain was harvested using a small plot grain harvester[7] when grain moisture was approximately 20%. Final grain yield was adjusted to 12% moisture content.

All data were subjected to the Mixed Procedure (SAS 2002). Years, locations, replications (nested within year), and all interactions were considered random effects. This allowed inferences to be made about herbicide treatments over a range of environments (Carmer et al. 1989). Herbicide treatments were considered fixed effects. Type III statistics were used to test all possible effects of fixed effects. Least-square means were used to determine mean separation at the $p \leq 0.05$ level.

RESULTS AND DISCUSSION

At 14 DAT, alligatorweed suppression was <69% from propanil tank mixed with penoxsulam at 30 g/ha or triclopyr applied EPOST or LPOST (Table 6). Penoxsulam alone provided 86% control EPOST, however, only 78% LPOST on larger alligatorweed. When penoxsulam was mixed with triclopyr, control was 89 and 81% EPOST and LPOST, respectively. Therefore, possible antagonism between penoxsulam and propanil may exist. Addition of halosulfuron with penoxsulam provided 78% control, similar to penoxsulam alone LPOST. Treatments including bispyribac sodium and bensulfuron alone or mixed with propanil and quinclorac plus propanil plus halosulfuron LPOST provided <65% alligatorweed control (Table 6). At 42 DAT, control from propanil mixed with penoxsulam or triclopyr was <68%. At 42 DAT, alligatorweed control was 79 and 83% from penoxsulam alone or when mixed with triclopyr EPOST (Table 6). LPOST applications of penoxsulam and bispyribac-sodium alone and with triclopyr were consistent with 81 to 92% control. LPOST applications are possibly providing longer residual activity. Penoxsulam plus halosulfuron and

Table 6. Alligatorweed control and rice grain yield from penoxsulam at 30 g ai/ha in different weed-control programs in drill-seeded rice in 2004 and 2005[a].

			Alligatorweed		
Herbicide treatment	Rate[b]	Timing[c]	14 DAT	42 DAT	Yield
	g ai/ha		% control		kg/ha
Non-treated			0 j[d]	0 h	7587 f
Penoxsulam	30	EPOST	86 ab	79 cd	9280 ab
+ propanil	3362	EPOST	68 de	65 ef	9055 a-d
+ triclopyr	210	EPOST	89 a	83 abc	9552 a
Propanil + triclopyr	3362 + 210	EPOST	56 fgh	57 fg	8766 bcd
Penoxsulam	30	LPOST	78 bcd	85 abc	8844 a-d
+ propanil	3362	LPOST	55 f-i	67 ef	8503 cd
+ triclopyr	210	LPOST	81 abc	91 ab	9322 ab
Propanil + triclopyr	3362 + 210	LPOST	61 efg	66 ef	8476 cde
Bispyribac-sodium	28	LPOST	64 ef	81 cd	9016 a-d
+ propanil	3362	LPOST	53 ghi	60 f	8439 cde
+ triclopyr	210	LPOST	83 ab	92 a	8992 a-d
Bensulfuron	70	LPOST	49 hi	50 g	7746 ef
Bensulfuron + propanil	70 + 3362	LPOST	57 fgh	61 f	8395 de
Prosulfuron	20	LPOST	71 cde	79 cd	8666 bcd
Quinclorac + propanil + halosulfuron	336 + 3362 + 33	LPOST	45 i	73 de	8999 a-d

Table 6. Continued.

Herbicide treatment	Rate[b]	Timing[c]	Alligatorweed 14 DAT	Alligatorweed 42 DAT	Yield
	g ai/ha		% control		kg/ha
Penoxsulam + halosulfuron	30 + 33	LPOST	78 bc	82 bcd	9175 ab

[a] Data were averaged over the five environments at Eagle Lake, Ganado, Garwood, and Lissie, TX in 2004 and 2005.

[b] Rate of penoxsulam is less than the labeled rate of 35 g ai/ha.

[c] Abbreviations: DAT,days after late postemergence treatment; EPOST, early postemergence (3-leaf rice); LPOST, late postemergence (4- to 5-leaf rice).

[d] Means within columns for each DAT followed by different letters are significantly different at $p \leq 0.05$.

prosulfuron provided 82 and 79% control, respectively, however, <73% control from treatments of quinclorac plus propanil plus halosulfuron, bensulfuron alone or bensulfuron plus propanil.

In 2006 when a higher labeled rate of penoxsulam at 35 g ai/ha was used, trends were similar to data obtained in 2004 and 2005 (Table 7). At 14 DAT, alligatorweed control ranged from 86 to 95%. Prosulfuron, bensulfuron, and bensulfuron plus propanil provided <84% control. By 42 DAT, control declined from all propanil tank mixes providing <73% control (Table 7). Penoxsulam alone and mixed with triclopyr EPOST and LPOST, bispyribac-sodium plus triclopyr, penoxsulam plus halosulfuron, and bispyribac-sodium plus Dyne-A-Pak LPOST, provided >80% control. Differences between EPOST and LPOST applications were less evident with penoxsulam at 35 g ai/ha with the exception of penoxsulam plus triclopyr LPOST at 94% (Table 7). Antagonistic effect of propanil on penoxsulam, bispyribac-sodium, and triclopyr was evident in both studies. Using Dyne-A-Pak as a surfactant with bispyribac-sodium provided 89% alligatorweed control. Bispyribac-sodium + kinetic alone or with UAN, data not shown, provided 73 and 74% control, respectively.

Rice grain yield in 2004 and 2005 ranged from 7587 to 9552 kg/ha. Penoxsulam alone or with triclopyr EPOST or LPOST, halosulfuron, and bispyribac-sodium LPOST, yielded highest, Treatments including propanil mixed with penoxsulam, triclopyr, bispyribac-sodium, or bensulfuron, and bensulfuron alone LPOST (Table 6) yielded lower. Penoxsulam plus propanil had high yield despite alligatorweed control of 65% applied EPOST. Lowest yielding treatments included bensulfuron alone or with

Table 7. Alligatorweed control and rice grain yield from penoxsulam at 35 g ai/ha in different weed-control programs in drill-seeded rice in 2006[a].

Herbicide treatment	Rate	Timing[b]	Alligatorweed 14 DAT	Alligatorweed 42 DAT	Yield
	g ai/ha		% control	% control	kg/ha
Untreated			0 g[c]	0 m	5523 f
Penoxsulam	35	EPOST	88 a-e	84 bcd	6515 a-d
+ propanil	3362	EPOST	90 a-d	70 fgh	6736 a-d
+ triclopyr	210	EPOST	92 ab	84 bcd	6520 a-d
Propanil + triclopyr	3362 + 210	EPOST	92 ab	57 jk	6454 b-e
Penoxsulam	35	LPOST	86 b-e	86 a-d	6972 ab
+ propanil	3362	LPOST	93 ab	73 efg	6930 ab
+ triclopyr	210	LPOST	87 a-e	94 a	6699 a-d
Propanil + triclopyr	3362 + 210	LPOST	95 a	61 hij	6355 cde
Bispyribac-sodium	28	LPOST	90 a-d	73 efg	6519 a-d
+ Dyne-A-Pak	1% v/v	LPOST	95	89	6850 a-d
+ propanil	3362	LPOST	95 a	60 ij	6817 a-d
+ triclopyr	210	LPOST	92 ab	92 ab	6477 b-e
Bensulfuron	70	LPOST	82 def	48 l	5928 ef
Bensulfuron + propanil	70 + 3362	LPOST	83 c-f	51 kl	6730 a-d
Prosulfuron	20	LPOST	76 f	78 def	6286 de

Table 7. Continued.

			Alligatorweed		
Herbicide treatment	Rate	Timing[b]	14 DAT	42 DAT	Yield
	g ai/ha		—% control—		—kg/ha—
Quinclorac + propanil + halosulfuron	336 + 3362 + 33	LPOST	90 abc	68 ghi	6951 ab
Penoxsulam + halosulfuron	35 + 33	LPOST	80 ef[c]	80 cde	6621 a-d

[a] Data were averaged over two locations at Eagle Lake in 2006.

[b] Abbreviations: DAT,days after late postemergence treatment; EPOST, early postemergence (3-leaf rice); LPOST, late postemergence (4-to 5- leaf rice).

[c] Means within columns for each DAT followed by different letters are significantly different at $p \leq 0.05$.

propanil and bispyribac-sodium + propanil.

Yield in 2006 ranged from 5523 to 6972 kg/ha. Bispyribac-sodium plus Kinetic plus UAN data not shown, penoxsulam alone or with propanil, and quinclorac plus propanil plus halosulfuron LPOST yielded highest, higher than propanil plus triclopyr EPOST and LPOST, bensulfuron, and prosulfuron LPOST (Table 7).

This research indicates that penoxsulam can be used in rice for adequate control of alligatorweed applied either EPOST or LPOST. Mixing penoxsulam with triclopyr enhanced control over penoxsulam alone, however, when mixed with propanil, control decreased significantly. Possible antagonism may exist with penoxsulam and propanil mixtures. Previous research has indicated propanil antagonism with other grass and broadleaf herbicides (Bauer et al. 1995a; Koo et al. 2000; Scherder et al. 2005). This may be due to the leaf burn and loss of membrane integrity from propanil by reducing absorption and translocation of penoxsulam. Adding halosulfuron did not increase control over penoxsulam alone. Differences between EPOST and LPOST applications were not significant except that penoxsulam at 35 g/ha plus triclopyr LPOST provided increased late season alligatorweed control. Bispyribac-sodium provided adequate alligatorweed control in 2004 and 2005 similar to penoxsulam, but not in 2006. Adding triclopyr increased alligatorweed control but when mixed with propanil control decreased. Using Dyne-A-Pak in place of kinetic plus UAN, data not shown, with bispyribac-sodium enhanced control of alligatorweed. Bensulfuron with or without propanil, prosulfuron, and quinclorac plus propanil plus halosulfuron did not provide adequate alligatorweed control and reduced rice grain yield.

All season control of alligatorweed will not be achieved with presently used one herbicide application in Texas. Due to the large underground network of rhizomes, regrowth occurs soon after treatment. Adequate control can be achieved with certain herbicides and not adversely affect rice yield. Increasing the rate of penoxsulam did not overcome penoxsulam antagonism with propanil observed in 2004 and 2005. Applying propanil separately from penoxsulam may overcome antagonism but timing herbicide applications has yet to be determined.

CHAPTER IV

EFFECT OF TEMPERATURE AND PROPANIL ON PENOXSULAM EFFICACY, ABSORPTION, AND TRANSLOCATION IN ALLIGATORWEED

INTRODUCTION

Alligatorweed has become one of the ten most troublesome weeds of rice in Florida, Louisiana, and Texas (Webster 2000; 2004). Effective control but not eradication, has been obtained with several rice herbicides without serious damage to the crop (Braverman and Jordan 1996; Carey et al. 2000; Pellerin et al. 2004; Webster et al. 1999; Webster et al. 2003). Due to the large underground network of rhizomes in the terrestrial form, regrowth occurs soon after herbicide application (Julien and Broadbent 1980). Glyphosate caused desiccation of alligatorweed foliage but showed limited translocation to roots (Bowmer et al. 1993; Tucker et al. 1994). Imazapyr, an acetolactate synthase (ALS) inhibitor, provided greater translocation to roots and long-term control without regrowth. Translocation to roots of pitted morningglory (*Ipomoea lacunosa* L.) was less than 1% from chlorimuron and imazaquin and 11% from imazethapyr (Kent et al. 1991; Shaw and Wesley 1993). Herbicide movement could be affected by changes in relative sink strength of roots and shoots during establishment and growth of perennials. Decreased translocation of herbicide to the roots could allow persistence of perennial species like alligatorweed.

Penoxsulam is a sulfonamide herbicide registered in 2005 for postemergence (POST) weed control in rice. Since the use of multiple crop protection pesticides is often needed for control of a variety of pests in rice, new herbicide combinations must be tested for antagonism due to the variability between herbicides within a family and between weed species. Antagonism has been observed between various graminicides mixed with broadleaf herbicides (Holshouser and Coble 1990; Vidrine et al. 1995). Efficacy of fenoxaprop was reduced when mixed with bentazon and triclopyr on grasses and when mixed with propanil and halosulfuron on barnyardgrass (*Echinochloa crus-galli*), but not on broadleaf signalgrass (*Urochloa platyphylla*) or Amazon sprangletop (*Leptochloa panicoides*) (Buehring et al. 2006; Jordan 1995; Stauber et al. 1991). Cyhalofop displayed antagonism with the three broadleaf herbicides triclopyr, propanil, and halosulfuron on both propanil-resistant and susceptible populations of barnyardgrass and broadleaf signalgrass (Scherder et al. 2005).

Reductions in efficacy when graminicides are mixed with ALS or photosystem II (PS II) herbicides have been partially explained by reductions in herbicide absorption and translocation. Propanil reduced the translocation of cyhalofop out of the treated leaf in barnyardgrass when combined and when propanil was applied 1 day before cyhalofop (Scherder et al. 2005). This may be due to the leaf burn and loss of membrane integrity. Propanil is a broad spectrum herbicide used in rice that inhibits the Hill reaction at PS II causing chlorosis within a few days (Senseman 2007). Bentazon, similar to propanil, is known to reduce sucrose production and translocation by inhibition of electron transport in PS II (Fuerst and Norman 1991). Penoxsulam, a phloem-mobile herbicide, may be inhibited when translocation and sucrose production is also inhibited by propanil (Devine et al. 1990). Bentazon decreased absorption and translocation of imazethapyr in

“Olathe” pinto bean (*Phaseolus vulgaris*), common ragweed (*Ambrosia artemisiifolia*) and redroot pigweed (*Amaranthus retroflexus* L.) (Bauer et al. 1995a; Bauer et al. 1995b; Hager et al. 1999). Pyribenzoxim translocation was reduced when applied to barnyardgrass in combination with propanil (Koo et al. 2000). Withpenoxsulam, tank mixes with various herbicides such as propanil have been evaluated for efficacy. Antagonism has not been identified except for alligatorweed control (O’Barr et al. 2004). Possible antagonism between propanil and penoxsulam may be a result of translocation reduction from reduced sucrose production from propanil inhibiting predominately phloem-mobile herbicides.

Antagonism has been successfully alleviated by increasing application rates of the antagonized herbicide as well as by applying the herbicides sequentially with herbicide applications separated by a few days (Culpepper et al. 1998; Palmer et al. 2000). Bromoxynil antagonistic effect on quizalofop for large crabgrass (*Digitaria sanguinalis*) and yellow foxtail (*Setaria glauca*) control was minimized when bromoxynil was applied 6 d prior or 3 d after (Culpepper et al. 1999). Corkern et al. (1998) reported that bromoxynil antagonism was reduced when applied 3 d prior or 7 d after the fluazifop application. Triclopyr and halosulfuron antagonism to cyhalofop was reduced when applied at least 3 d before or after cyhalofop on propanil-resistant and susceptible barnyardgrass and broadleaf signalgrass. However propanil was antagonistic when tank mixed with cyhalofop (Scherder et al. 2005). Sequential application increased control. Propanil treated 1 d prior through 5 d after pyribenzoxim application was antagonistic on barnyardgrass and showed greater antagonism with shorter intervals between applications (Koo et al. 2000). Increasing the rate of the antagonized herbicide had little effect on the amount of antagonism without reaching control equal to the single application (Barnes and Oliver 2004; Culpepper et al. 1999; Koo et al. 2000).

Environmental conditions at application may alter the efficacy of herbicides by changing absorption and translocation (Coupland 1983; Kudsk et al. 1990). Temperature and soil moisture can cause plant stress influencing leaf cuticular composition and foliar penetration, thereby, decreasing the activity of herbicides (Hsaio 1973; Hull et al. 1975). Foliar application of imazamethabenz controlled wild oat greater at 16/10 C (day/night) than at 11/7 C or 26/16 C compared to blackgrass (*Alopecurus myosuroides*) with greater control at 26/16 C (Shaner and O'Connor 1991). Glyphosate applications to quackgrass (*Elymus repens*) provided greater control as temperature, humidity, and light increased (Coupland 1983). Geier et al. (1999) reported that plant dry weight reduction was greater at 10/5 C than at 21/7 C for cheat (*Bromus secalinus*), however, just the opposite for wheat (*Triticum aestivum*) at 7% soil moisture from sulfosulfuron.

Absorption and translocation can also be deterred by temperature and soil moisture and can vary between weed species and/or herbicides. Translocation of pyrithiobac in velvetleaf (*Abutilon theophrasti*), metribuzin in jointed goatgrass (*Aegilops cylindrical*), downy brome (*Bromus tectorum*), and wheat, and atrazine in common bean and redroot pigweed was greater at higher temperatures (30 to 25 C) and soil moistures (field capacity and ¾ field capacity) (Al-Khatib et al. 1992; Buman et al. 1992; Harrison et al.

1996). In contrast, wheat and wild oat absorbed and translocated more sulfosulfuron at lower temperatures, 15/13 C, however, downy brome was unaffected (Olson et al. 1999).

With possible antagonism between propanil and penoxsulam in alligatorweed based on field studies, (O'Barr et al 2004; Willingham et al. unpublished 2008), application procedures must be evaluated to determine if propanil is actually inhibiting absorption and translocation of penoxsulam in alligatorweed. The objective of this study was to determine the absorption and translocation efficiency of penoxsulam and the effect of propanil on penoxsulam in alligatorweed and to access application timing and air temperature effects on penoxsulam efficacy to avoid antagonism with propanil.

MATERIALS AND METHODS

Effect of Temperature and Sequential Applications. Alligatorweed was planted in 15 cm diameter plastic pots containing Metro Mix 200[8] potting soil using stem pieces approximately 3cm long containing one node. Eight nodes were planted per pot and grown at 30/25 C day/night temperatures with a 14-h photoperiod and watered as needed. Lighting was supplied by low pressure sodium vapor lamps[9], VHO fluorescent bulbs[10], and clear incandescent bulbs[11], leading to a photosynthetic photon flux density (PPFD) of 1,100 µmol/m^{2}s. Plants were grown to a height of 20 to 25 cm containing seven to eight leaf pairs, and were transferred to growth chambers at 30/25, 27/18, and 21/11 C day/night temperatures providing a 14-h photoperiod. Plants were allowed to acclimate to the temperature for 5 d before herbicide application. Herbicide treatments consisted of either non-treated, penoxsulam at 0.035 kg ai/ha, propanil at 3.36 kg/ha, penoxsulam plus propanil, penoxsulam followed by (fb) propanil at 3, 5, or 10 d after penoxsulam. Treatments were applied with a CO_2 backpack sprayer delivering 140 L/ha of water at 202 kPa pressure through a TeeJet flat-fan 8002 spray tip[12] and included a crop oil concentrate[13] at 1% (v/v).

The study was designed as a split-plot with four replications and the experiment was repeated. Trial effects were not significant, therefore, data were pooled over experiments. The main plot was temperature and sub-plots were herbicide treatments. Data collection consisted of visual estimation of control at 21 days after treatment (DAT) as a function of visual biomass reduction, with 0% indicating no control, and 100% indicating complete control. At 42 DAT, percent biomass reduction was determined by harvesting the above-ground biomass and converting the fresh weight to a percent reduction based on the non-treated control.

All data were subjected to the Mixed Procedure using SAS 2002. Herbicide treatments, temperature regimes, and their interactions were considered fixed effects. Type III statistics were used to test all possible effects of fixed effects along with Fisher's protected LSD to determine mean separation at the $p \leq 0.05$ level.

Propanil Effects on Absorption and Translocation of Penoxsulam. Alligatorweed nodes were planted in 3.8-cm diameter x 21-cm deep cones containing potting mix. Plants were grown in growth chambers with a 14-h photoperiod and 30 C day/25 C night temperature regime. Plants were watered daily and fertilized bi-weekly with a nutrient solution[14]. Treatments for efficacy and absorption/translocation determinations were applied to 20 to 25 cm tall alligatorweed plants containing seven to eight leaf pairs. This growth stage was used to simulate plants typically present at early postemergence (EPOST) herbicide treatments. Treatments consisted of penoxsulam at 0.035 kg/ha plus a crop oil concentrate at 1% v/v and penoxsulam at 0.035 kg/ha plus propanil at 3.36 kg/ha applied with a CO_2 backpack sprayer delivering 140 L/ha of water. Within 0.5 h following application of the formulated products, 6 µL of ^{14}C-2-benzene labeled penoxsulam with 950 kBq/µmol specific activity and 99.1% radiochemical purity solution was applied in three 1-µL drops to the adaxial leaf surface of each leaf of the fourth leaf pair. Plants were maintained in a growth chamber until harvest.

Plants were harvested 1, 12, 24 and 48 h after treatment (HAT) with ^{14}C-penoxsulam. The treated leaf pair was excised and ^{14}C-penoxsulam remaining on the leaf surface was removed by washing in 3 ml of deionized water for 5 s. The treated leaf was washed in 3 ml of methanol for 5 s to remove ^{14}C-penoxsulam from the epicuticular wax. Plants were sectioned into treated leaf, portion of plant above treated leaf, portion of plant below treated leaf, and roots. Plant portions were placed in paper coin envelopes and dried at 55 C for 72 h. Three ml of liquid scintillation cocktail[15] was added to the leaf washes for quantification by liquid scintillation spectrometry[16]. Oven-dried plant samples were combusted with a biological sample oxidizer[17]. Sample radioactivity was quantified by liquid scintillation spectrometry.

The sum of ^{14}C-penoxsulam located in leaf washes and plant sections was considered as total ^{14}C recovered, which averaged 94% of applied ^{14}C-penoxsulam. The amount of radioactivity located in the water wash, methanol wash, treated leaf, above treated leaf, below treated leaf, and roots was expressed as a percentage of recovered radioactivity.

Treatments were replicated four times and the experiment was repeated. Treatments were arranged in a randomized complete block design. Data were pooled across experiment because the treatment by experiment interaction was not significant. Treatments were subjected to ANOVA and means were separated by Fisher's protected LSD test at the 5% level of probability.

RESULTS AND DISCUSSION

Effect of Temperature and Sequential Applications. A temperature by treatment interaction occurred for alligatorweed control and biomass reduction. Therefore, data were presented to reflect the interaction (Table 8). At 21 DAT, alligatorweed control at 21/11 C was above 92% from penoxsulam alone and 95% after penoxsulam fb propanil at 3, 5, or 10 DAT. Delaying propanil treatment at least 3 d after penoxsulam application provided control equal to penoxsulam alone. With temperatures at 27/18 C, control was 80% from penoxsulam alone and similar when propanil application was delayed 3 d. Increased control was achieved from delaying propanil application at least 5 d. At 30/25 C, control was 73 to 77% from penoxsulam alone and when propanil was delayed 3 or 5 d but delaying propanil application 10 d was required to provide control greater than penoxsulam alone. Propanil alone provided less than 60% control independent of temperature. Tank mixes of propanil plus penoxsulam provided 83% control at 21/11 C and less than 67% at 27/18 or 30/25 C (Table 8).

As temperatures were increased, alligatorweed control from penoxsulam alone

Table 8. Alligatorweed control 21 days after treatment as effected by temperature and herbicide application timing.

Herbicide treatments	Timing [a]	Temperature regime [b] 21/11	27/18	30/25
		—% —		
Penoxsulam	alone	93 Aa [c]	80 Bb	73 Bc
Propanil	alone	47 Cb	35 Dc	58 Da
Penoxsulam +propanil	tank mix	83 Ba	63 Cb	66 Cb
Penoxsulam fb propanil	3 d after	95 Aa	80 Bb	77 Bb
Penoxsulam fb propanil	5 d after	95 Aa	88 Aa	74 Bb
Penoxsulam fb propanil	10 d after	95 Aa	92 Aa	88 Ab

[a.] Timing represents the application timing of propanil relative to the application of penoxsulam to 20 to 25 cm tall alligatorweed.

[b.] Temperature regime represents day (first number) and night (second number) temperatures in degrees C.

[c.] Means followed by the same uppercase letter within columns for each temperature regime and means followed by the same lowercase letter within each treatment are not significantly different using Fisher's protected LSD at $p \leq 0.05$.

decreased from 93% to 73% (Table 8). Delaying propanil application 3 d after penoxsulam provided 95% control at 21/11 C compared to 80% at 27/18 C and 77% at 30/25 C. Propanil applied 5 d after penoxsulam provided 95% control at 21/11 C and 88% at 27/18 C compared to 30/25 C at 74% control. When propanil was delayed 10 d after penoxsulam, control was 88 to 95%.

At 42 DAT, percent biomass reduction at 21/11 C was greater than 95% from penoxsulam alone and from sequential applications of penoxsulam fb propanil delayed 3, 5, or 10 d (Table 9). Propanil alone and penoxsulam plus propanil tank mixed provided 51 and 83% biomass reduction, respectively. At temperatures of 27/18 C, biomass reduction was similar at 75 to 77% for penoxsulam alone compared to penoxsulam fb delaying propanil 3 or 5 d. Delaying propanil application 10 d provided biomass reduction greater than 90%. At 30/25 C, delaying propanil 10 d after penoxsulam provided biomass reduction similar to penoxsulam alone at 69 and 73%, respectively. Treatments of propanil alone or when tank mixed with penoxsulam provided less than 60% biomass reduction (Table 9).

Biomass reduction from penoxsulam alone decreased as temperature increased from 100% at 21/11 C to 73% at 30/25 C (Table 9). Delaying propanil application 3 and 5 d after penoxsulam provided at least 95% biomass reduction at 21/11 C. As temperature was increased, percent biomass decreased from 75 and 77% at 27/18 C to 59 and 49% at 30/25 C. Delaying propanil 10 d provided similar biomass reduction of 96% at 21/11 C and 91% at 27/18 C compared to 69% biomass reduction at 30/25 C. Propanil

Table 9. Alligatorweed biomass reduction[a] 42 days after treatment as effected by temperature and herbicide application timing.

Herbicide treatments	Timing[c]	Temperature regimes[b]		
		21/11	27/18	30/25
		%		
Penoxsulam	alone	100 Aa[d]	77 Bb	73 Ab
Propanil	alone	51 Ca	29 Db	52 Ca
Penoxsulam +propanil	tank mix	83 Ba	48 Cb	56 Bb
Penoxsulam fb propanil	3 d after	96 Aa	75 Bb	59 Bc
Penoxsulam fb propanil	5 d after	97 Aa	77 Bb	49 Cc
Penoxsulam fb propanil	10 d after	96 Aa	91 Aa	69 Ab

[a.] Alligatorweed biomass reduction – ((biomass non-treated plants- biomass treated plants)/biomass non-treated plants) *100.

[b.] Temperature regime represents day (first number) and night (second number) temperatures in degrees C.

[c.] Timing represents the application timing of propanil relative to the application of penoxsulam to 20 to 25 cm tall alligatorweed.

[d.] Means followed by the same uppercase letter within columns for each temperature regime and means followed by the same lowercase letter within each treatment are not significantly different using Fisher's protected LSD at $p \leq 0.05$.

alone provided less than 53% biomass reduction independent of temperature. Tank mix of propanil plus penoxsulam provided 83% reduction at 21/11 C, 48% at 27/18 C and 56% at 30/25 C (Table 9). Reduced alligatorweed control suggests that these two products are antagonistic and should not be used in a tank mixture.

Propanil Effects on Absorption and Translocation of Penoxsulam. The amount of ^{14}C penoxsulam in the leaf washes was different among treatments and decreased as time after application increased (Table 10). At 1 and 12 HAT, over 90% of ^{14}C penoxsulam was in leaf washes. More ^{14}C penoxsulam remained on the leaf surface from penoxsulam alone compared to penoxsulam plus propanil. The addition of propanil allowed more radiolabeled penoxsulam to enter the cuticle of the leaf possibly due to the caustic nature of propanil. There were no differences among treatments in the plant sections. By 24 and 48 HAT, more ^{14}C penoxsulam remained on the leaf surface from the addition of propanil compared to penoxsulam alone (Table 10).

Within the cuticle of the leaf, amounts of ^{14}C penoxsulam were similar among treatments (Table 10). The addition of propanil decreased the amount of ^{14}C penoxsulam absorbed into the treated leaf compared to penoxsulam alone at both 24 and 48 HAT. Translocation of radiolabeled material out of the treated leaf to plant sections above and below the treated leaf and in the roots was less than 2% with no differences between treatments at any harvest interval. These results are similar to research conducted using glyphosate and imazapyr evaluating the amount translocated in alligatorweed (Bowmer et al. 1993; Bowmer and Eberbach 1993; Tucker et al. 1994). Less than 8% of applied glyphosate and imazapyr were translocated by 3 DAT.

Table 10. Distribution of ^{14}C- penoxsulam from treatments applied alone and with propanil at different time intervals following application to alligatorweed.

Treatment	Water wash	Methanol wash	TL[a]	Above TL	Below TL	Roots
	1 hour after treatment					
	% of recovered					
Penoxsulam	94.0 A[b]	3.4 B	1.1 A	0.2 A	0.4 A	0.4 A
Penoxsulam + propanil	90.4 B	7.8 A	0.6 A	0.4 A	0.3 A	0.2 A
	12 hours after treatment					
	% of recovered					
Penoxsulam	71.5 A	20.6 B	6.5 A	0.3 A	0.3 A	0.3 A
Penoxsulam + propanil	64.3 B	29.5 A	5.0 A	0.5 A	0.2 A	0.2 A
	24 hours after treatment					
	% of recovered					
Penoxsulam	57.1 B	27.0 A	14.4 A	0.4 A	0.3 A	0.5 A
Penoxsulam + propanil	63.6 A	25.7 A	8.1 B	1.5 A	0.4 A	0.3 A

Table 10. Continued.

	48 hour after treatment					
Treatment	Water wash	Methanol wash	TL[a]	Above TL	Below TL	Roots
	——% of recovered——					
Penoxsulam	43.5 B	22.9 A	29.3 A	1.3 A	1.5 A	1.2 A
Penoxsulam + propanil	52.1 A	24.8 A	18.6 B	1.6 A	1.1 A	1.3 A

[a] TL, Treated leaf.

[b] Means followed by the same uppercase letter within columns are not significantly different using Fisher's protected LSD at $P \leq 0.05$.

Percent biomass reduction of alligatorweed compared to non-treated plants was greatest at 21/11 C compared to 27/18 C and 30/25 C for all treatments. Weed control can be altered by temperature and soil moisture and can vary between weed species and/or herbicides (Coupland 1983; Geier et al. 1999; Shaner and O'Connor 1991). Propanil tanked mixed with penoxsulam provided less biomass reduction compared to penoxsulam alone independent of temperature. At 21 and 27 C, delaying propanil application at least 3 days after penoxsulam provided biomass reductions similar to penoxsulam applied alone. At 27 C, delaying propanil application 10 d achieved biomass reduction greater than penoxsulam alone. At 30 C, delaying propanil application 10 d after penoxsulam was required to achieve reductions similar to that of penoxsulam. When ^{14}C-penoxsulam was traced through alligatorweed, the addition of propanil reduced the amount of penoxsulam absorbed into the treated leaf. Initially, more ^{14}C-penoxsulam reached the cuticle with the addition of propanil, possibly due to the caustic leaf burn associated with propanil, resulting in loss of membrane integrity. Less than 2% of penoxsulam was translocated in alligatorweed by 48 HAT. Extending the time after treatment for harvest beyond 48 HAT would possibly result in greater ^{14}C-penoxsulam translocated to other plant sections.

CHAPTER V

SUMMARY AND CONCLUSIONS

Alligatorweed is a noxious weed in Texas that has migrated from waterways to the ditches and canals that supply irrigation water to rice fields. Alligatorweed is a perennial that produces a massive underground rhizome system difficult to control with herbicides. Control/suppression can be achieved throughout the growing season but regrows rapidly after suppression. Penoxsulam is a new herbicide for weed control in rice and a possible substitute for propanil and propanil-resistant weeds. A better understanding of penoxsulam behavior and environmental factors favoring its efficacy is needed. The objectives of this research were to: 1) evaluate the effects of select rice herbicides on alligatorweed control, 2) determine the absorption and translocation efficiency and the effect of propanil on penoxsulam in alligatorweed 3) access the environmental effects of temperature on penoxsulam efficacy and determine application timing to avoid antagonism with propanil and, 4) evaluate the effects of flood timing and rice cultivars on rice root stunting and plant foliar injury from penoxsulam applications.

Flood timing affected root growth for rice cultivars treated with penoxsulam and bispyribac-sodium. Flooding 1 or 7 DAT consistently resulted in greater root growth inhibition (RGI) than when flood was delayed to 14 DAT. The earlier the flood timing, the longer RGI persisted. By 4 WAT, rice plants recovered from initial herbicide injury. Grain yield for all cultivars was not adversely affected by initial herbicide injury. For the worse-case scenario more herbicide was available for plant uptake at flood 1 DAT.

RGI was greater with bispyribac-sodium for Bengal and Cypress when compared to penoxsulam at 30 g/ha. Differences between these treatments were not evident 1 week later. Penoxsulam at 30 and 60 g/ha and bispyribac-sodium initially inhibited root growth, however, rice plants recovered resulting in no yield reduction compared to the standard treatment. XP712 was most tolerant to herbicide treatments and flood timings with < 5% RGI and foliar injury. Hybrids such as XP712 inherently have higher yield potential than cultivars.

Penoxsulam can be used in rice for adequate control of alligatorweed applied either EPOST or LPOST. Mixing penoxsulam with triclopyr enhanced control over penoxsulam alone, however, when mixed with propanil, control decreased significantly. This may be due to the leaf burn and loss of membrane integrity from propanil therefore reducing translocation of penoxsulam. Increasing the rate of penoxsulam did not overcome the antagonism with propanil. Differences between EPOST and LPOST applications were not significant except that penoxsulam at 35 g/ha plus triclopyr LPOST provided increased late season control. Bispyribac-sodium provided adequate control most years but was variable. Adding triclopyr increased alligatorweed control but when mixed with propanil control decreased. Using Dyne-A-Pak, a surfactant containing methylated seed oil and UAN, in place of Kinetic plus UAN with bispyribac-sodium as the surfactant, enhanced control of alligatorweed. Complete control of alligatorweed all season can not be achieved with one herbicide application in Texas due to regrowth from the large underground network of rhizomes. Adequate control can be achieved with select herbicides and rice yield is not adversely affected.

Studies conducted in the growth chambers indicated percent biomass reduction of alligatorweed compared to non-treated was greatest at 21/11 C compared to 27/18 C and 30/25 C for treatments including penoxsulam and sequential applications of penoxsulam and propanil. Weed control can be altered by temperature and soil moisture and can vary between weed species and/or herbicides (Coupland 1983, Geier et al. 1999, Shaner and O'Connor 1991). Tank mixing propanil plus penoxsulam provided less biomass reduction compared to penoxsulam alone in the growth chambers, similar to field studies, independent of temperature. Delaying propanil application at least 3 days after penoxsulam provided % biomass reduction similar to penoxsulam alone. Delaying propanil application longer after penoxsulam will provide biomass reduction greater than penoxsulam alone. At 30 C, delaying propanil application 10 d after penoxsulam was required to achieve reduction similar to penoxsulam.

When radiolabeled penoxsulam was traced through alligatorweed, the addition of propanil reduced the amount of penoxsulam absorbed into the treated leaf by 48 HAT. Initially, more ^{14}C-penoxsulam reached the leaf cuticle with the addition of propanil, possibly due to the caustic leaf burn associated with propanil ultimately resulting in loss of membrane integrity in alligatorweed. Penoxsulam alone or mixed with propanil by 48 HAT resulted in less than 5% of ^{14}C-penoxsulam translocation. Penoxsulam is a useful tool providing adequate control of alligatorweed.

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APPENDIX A

CLIMATIC CONDITIONS AT TEXAS AGRICULTURAL RESEARCH AND EDUCATION CENTER NEAR EAGLE LAKE, TX.

2004 GROWING SEASON

2004

Date	Air Temperature (°F)		Precipitation (in)	Relative Humidity (%)	
	Max	Min		Max	Min
3/1/2004	60.0	50.0	0.02	93	36
3/2/2004	76.0	58.0	0.03	98	36
3/3/2004	74.0	64.0	0.04	98	67
3/4/2004	70.0	60.0	0.12	98	68
3/5/2004	73.0	49.0	0.00	98	19
3/6/2004	75.0	47.0	0.00	84	18
3/7/2004	78.0	46.0	0.00	78	19
3/8/2004	67.0	45.0	0.00	72	18
3/9/2004	74.0	38.0	0.00	80	18
3/10/2004	69.0	46.0	0.00	88	21
3/11/2004	70.0	48.0	0.00	98	21
3/12/2004	67.0	52.0	0.29	95	31
3/13/2004	63.0	55.0	0.95	98	66
3/14/2004	60.0	55.0	0.34	98	97
3/15/2004	72.0	54.0	0.01	98	34
3/16/2004	72.0	58.0	0.00	98	32
3/17/2004	78.0	60.0	0.00	90	32
3/18/2004	76.0	62.0	0.00	98	44
3/19/2004	78.0	60.0	0.00	98	43
3/20/2004	80.0	60.0	0.00	95	41
3/21/2004	71.0	47.0	0.07	91	38
3/22/2004	66.0	53.0	0.00	78	20
3/23/2004	67.0	58.0	0.00	86	35
3/24/2004	68.0	60.0	0.15	98	50
3/25/2004	73.0	63.0	0.01	98	43
3/26/2004	72.0	63.0	0.00	98	50
3/27/2004	75.0	66.0	0.00	98	45
3/28/2004	81.0	57.0	0.80	98	29
3/29/2004	64.0	46.0	0.02	93	34
3/30/2004	78.0	50.0	0.00	79	17
3/31/2004	82.0	48.0	0.00	82	17
4/1/2004	81.0	54.0	0.00	92	17
4/2/2004	77.0	54.0	0.45	98	32
4/3/2004	77.0	65.0	0.00	98	30
4/4/2004	75.0	58.0	0.00	98	29
4/5/2004	74.0	58.0	0.00	92	32
4/6/2004	66.0	57.0	0.27	98	56
4/7/2004	80.0	54.0	0.29	98	19
4/8/2004	74.0	55.0	0.00	92	23
4/9/2004	80.0	58.0	0.00	98	22

4/10/2004	82.0	48.0	1.43	98	22
4/11/2004	68.5	46.0	0.18	93	75
4/12/2004	55.0	40.0	0.15	93	37
4/13/2004	62.0	42.0	0.00	94	23
4/14/2004	70.0	44.0	0.00	94	20
4/15/2004	74.0	54.0	0.00	93	28
4/16/2004	79.0	61.0	0.00	98	29
4/17/2004	81.0	60.0	0.00	98	29
4/18/2004	76.0	63.0	0.00	98	27
4/19/2004	80.0	62.0	0.00	98	22
4/20/2004	81.0	65.0	0.00	96	31
4/21/2004	82.0	68.0	0.00	97	35
4/22/2004	82.0	66.0	0.00	97	35
4/23/2004	80.0	60.0	0.78	98	37
4/24/2004	74.0	64.0	0.18	98	37
4/25/2004	77.0	64.0	0.32	98	55
4/26/2004	78.0	54.0	0.00	89	27
4/27/2004	80.0	54.0	0.00	96	19
4/28/2004	76.0	60.0	0.02	96	30
4/29/2004	83.0	65.0	0.00	96	38
4/30/2004	82.0	55.0	1.05	98	46
5/1/2004	76.5	53.0	0.58	98	35
5/2/2004	71.0	51.0	0.00	79	20
5/3/2004	81.0	54.0	0.00	75	18
5/4/2004	81.0	58.0	0.00	92	20
5/5/2004	81.0	59.0	0.00	96	27
5/6/2004	82.0	62.0	0.00	95	27
5/7/2004	83.0	66.0	0.00	98	29
5/8/2004	77.0	67.0	0.10	98	49
5/9/2004	74.0	62.0	1.36	98	44
5/10/2004	83.0	67.0	1.50	98	38
5/11/2004	77.0	65.0	0.49	98	55
5/12/2004	83.0	73.0	0.06	98	53
5/13/2004	82.0	62.0	2.33	92	55
5/14/2004	75.0	59.0	0.00	94	43
5/15/2004	79.0	62.0	0.00	96	36
5/16/2004	84.0	66.0	0.00	98	29
5/17/2004	85.0	68.0	0.20	98	37
5/18/2004	87.0	68.0	0.02	98	32
5/19/2004	88.0	70.0	0.00	98	28
5/20/2004	87.0	69.0	0.00	98	29
5/21/2004	85.0	69.0	0.00	98	31
5/22/2004	86.0	68.0	0.00	98	27
5/23/2004	86.0	68.0	0.00	98	29
5/24/2004	88.0	70.0	0.00	98	27

5/25/2004	88.0	69.0	0.00	96	29
5/26/2004	86.0	68.0	0.00	96	28
5/27/2004	90.0	72.0	0.00	97	27
5/28/2004	90.0	73.0	0.00	97	30
5/29/2004	87.0	76.0	0.00	94	38
5/30/2004	87.0	77.0	0.01	95	49
5/31/2004	93.0	70.0	0.01	95	31
6/1/2004	94.0	70.0	0.00	95	30
6/2/2004	92.0	66.0	0.06	97	29
6/3/2004	90.0	67.0	0.00	96	26
6/4/2004	93.0	65.0	0.30	96	27
6/5/2004	90.0	71.0	0.00	97	26
6/6/2004	90.0	73.0	0.00	97	25
6/7/2004	91.0	68.0	1.64	98	27
6/8/2004	80.0	70.0	1.59	92	66
6/9/2004	86.0	75.0	0.07	97	41
6/10/2004	88.0	73.0	0.42	96	34
6/11/2004	88.0	74.0	0.14	96	36
6/12/2004	89.0	74.0	0.01	98	31
6/13/2004	91.0	69.0	0.02	98	29
6/14/2004	89.0	74.0	0.01	98	31
6/15/2004	90.0	70.0	0.00	98	25
6/16/2004	81.0	68.0	0.06	98	57
6/17/2004	82.0	72.0	0.25	98	53
6/18/2004	88.0	72.0	0.82	98	38
6/19/2004	91.0	72.0	0.00	97	29
6/20/2004	91.0	73.0	0.00	93	24
6/21/2004	92.0	73.0	0.00	96	24
6/22/2004	92.0	75.0	0.00	95	27
6/23/2004	82.0	72.0	0.40	96	59
6/24/2004	78.0	72.0	2.18	97	59
6/25/2004	81.0	69.0	0.31	98	62
6/26/2004	81.0	67.0	1.72	98	54
6/27/2004	83.0	73.0	0.01	96	40
6/28/2004	89.0	73.0	0.38	97	34
6/29/2004	88.0	73.0	0.01	97	38
6/30/2004	84.0	72.0	0.41	97	51
7/1/2004	82.0	73.0	0.15	97	67
7/2/2004	89.0	74.0	0.00	96	32
7/3/2004	91.0	74.0	0.00	95	26
7/4/2004	91.0	72.0	0.00	95	30
7/5/2004	91.0	74.0	0.00	92	26
7/6/2004	92.0	73.0	0.00	95	28
7/7/2004	94.0	73.0	0.00	95	25
7/8/2004	90.0	68.0	0.00	95	26

7/9/2004	93.0	73.0	0.00	94	26
7/10/2004	86.0	69.0	0.00	95	42
7/11/2004	87.0	71.0	0.63	95	33
7/12/2004	89.0	71.0	0.43	94	31
7/13/2004	92.0	71.0	0.00	95	26
7/14/2004	93.0	72.0	0.00	95	21
7/15/2004	95.0	73.0	0.00	79	20
7/16/2004	94.0	73.0	0.00	86	20
7/17/2004	93.0	74.0	0.00	90	23
7/18/2004	93.0	72.0	0.00	93	25
7/19/2004	90.0	70.0	0.00	86	20
7/20/2004	91.0	71.0	0.00	93	23
7/21/2004	92.0	71.0	0.00	94	29
7/22/2004	92.0	72.0	0.06	95	26
7/23/2004	92.0	72.0	0.00	96	27
7/24/2004	93.0	72.0	0.21	96	25
7/25/2004	93.0	74.0	0.00	84	20
7/26/2004	96.0	69.0	0.10	92	19
7/27/2004	87.0	68.0	0.00	94	30
7/28/2004	91.0	69.0	0.00	95	26
7/29/2004	94.0	74.0	0.00	95	26
7/30/2004	96.0	74.0	0.00	95	20
7/31/2004	96.0	74.0	0.00	91	19
8/1/2004	95.0	75.0	0.00	87	22
8/2/2004	97.0	73.0	0.00	90	23
8/3/2004	96.0	75.0	0.00	93	21
8/4/2004	96.0	73.0	0.00	92	19
8/5/2004	97.0	75.0	0.00	90	16
8/6/2004	99.0	76.0	0.00	90	16
8/7/2004	90.0	69.0	0.00	84	29
8/8/2004	89.0	68.0	0.00	85	22
8/9/2004	92.0	71.0	0.00	84	18
8/10/2004	95.0	73.0	0.00	83	15
8/11/2004	92.0	73.0	0.00	89	26
8/12/2004	95.0	68.0	0.03	91	18
8/13/2004	95.0	61.0	0.00	84	17
8/14/2004	87.0	64.0	0.00	86	18
8/15/2004	87.0	63.0	0.00	87	17
8/16/2004	88.0	62.0	0.00	88	17
8/17/2004	90.0	62.0	0.00	89	16
8/18/2004	91.0	64.0	0.00	90	17
8/19/2004	95.0	68.0	0.00	95	19
8/20/2004	96.0	74.0	0.00	96	20
8/21/2004	98.0	71.0	0.06	93	18
8/22/2004	88.0	73.0	0.12	96	18

8/23/2004	92.0	73.0	0.27	93	27
8/24/2004	92.0	74.0	0.05	95	35
8/25/2004	97.0	75.0	0.00	95	18
8/26/2004	98.0	76.0	0.00	94	22
8/27/2004	98.0	72.0	0.00	94	17
8/28/2004	97.0	73.0	0.00	94	21
8/29/2004	92.0	71.0	0.00	94	27
8/30/2004	86.0	71.0	0.00	94	27
8/31/2004	92.0	70.0	0.00	92	16
9/1/2004	90.0	65.0	0.00	89	20
9/2/2004	88.0	65.0	0.00	92	18
9/3/2004	82.0	57.0	0.02	95	28
9/4/2004	82.0	69.0	0.00	95	42
9/5/2004	89.0	69.0	0.00	96	29
9/6/2004	94.0	71.0	0.00	95	23
9/7/2004	95.0	71.0	0.00	96	18
9/8/2004	82.0	72.0	0.00	94	31
9/9/2004	87.0	66.0	0.00	93	18
9/10/2004	89.0	66.0	0.00	91	16
9/11/2004	93.0	68.0	0.00	89	17
9/12/2004	93.0	70.0	0.00	87	18
9/13/2004	95.0	71.0	0.00	92	15
9/14/2004	90.0	71.0	0.00	95	28
9/15/2004	90.0	71.0	3.50	95	34
9/16/2004	92.0	73.0	0.00	96	25
9/17/2004	94.0	73.0	0.00	91	17
9/18/2004	95.0	72.0	0.00	94	17
9/19/2004	96.0	71.0	0.00	96	16
9/20/2004	92.0	66.0	0.00	88	17
9/21/2004	89.0	66.0	0.00	92	18
9/22/2004	80.0	65.0	0.00	95	37
9/23/2004	87.0	67.0	0.01	95	30
9/24/2004	90.0	67.0	0.00	95	18
9/25/2004	88.0	67.0	0.00	96	27
9/26/2004	87.0	66.0	0.00	96	27
9/27/2004	89.0	65.0	0.00	85	18
9/28/2004	85.0	65.0	0.00	85	19
9/29/2004	90.0	62.0	0.00	88	16
9/30/2004	89.0	62.0	0.00	91	17

APPENDIX B

CLIMATIC CONDITIONS AT TEXAS AGRICULTURAL RESEARCH AND EDUCATION CENTER NEAR EAGLE LAKE, TX.

2005 GROWING SEASON

2005

Date	Air Temperature (°F)		Precipitation (in)	Relative Humidity (%)	
	Max	Min		Max	Min
3/1/2005	66.0	46.0	0.01	98	24
3/2/2005	71.0	46.0	0.00	98	24
3/3/2005	59.0	46.0	1.35	98	74
3/4/2005	58.0	44.0	0.01	98	47
3/5/2005	71.0	46.0	0.00	98	45
3/6/2005	70.0	47.0	0.29	98	31
3/7/2005	70.0	47.0	0.11	98	72
3/8/2005	71.0	47.0	0.44	98	33
3/9/2005	67.0	49.0	0.00	74	19
3/10/2005	72.0	47.5	0.00	81	19
3/11/2005	77.0	46.0	0.00	87	18
3/12/2005	73.0	48.0	0.00	85	17
3/13/2005	80.0	52.0	0.00	82	31
3/14/2005	87.0	44.0	0.00	78	17
3/15/2005	68.0	47.0	0.00	73	21
3/16/2005	59.0	44.0	0.35	90	32
3/17/2005	52.0	38.0	0.07	90	35
3/18/2005	62.0	40.0	0.00	82	22
3/19/2005	75.0	49.0	0.01	94	20
3/20/2005	81.0	53.0	0.42	96	21
3/21/2005	73.0	58.0	0.00	97	29
3/22/2005	77.0	62.0	0.00	97	37
3/23/2005	77.0	46.0	0.00	94	16
3/24/2005	75.0	51.0	0.00	96	19
3/25/2005	80.0	57.0	0.00	94	19
3/26/2005	82.0	63.0	0.00	98	22
3/27/2005	73.0	47.0	0.21	95	33
3/28/2005	59.0	42.0	0.00	90	24
3/29/2005	76.0	48.0	0.00	92	18
3/30/2005	75.0	59.0	0.00	92	33
3/31/2005	85.0	64.0	0.00	97	17
4/1/2005	79.0	55.0	0.00	84	23
4/2/2005	75.0	55.0	0.00	83	19
4/3/2005	74.0	44.0	0.00	82	63
4/4/2005	76.0	57.0	0.00	83	63
4/5/2005	76.0	59.0	0.00	89	51
4/6/2005	78.0	57.0	0.12	95	38
4/7/2005	78.0	54.0	0.00	83	18
4/8/2005	78.0	54.0	0.00	83	18
4/9/2005	81.0	54.0	0.00	97	18

4/10/2005	82.0	63.0	0.00	97	28
4/11/2005	78.0	68.0	0.86	97	38
4/12/2005	77.0	46.0	0.00	97	48
4/13/2005	81.0	50.0	0.00	80	15
4/14/2005	83.0	51.0	0.00	82	15
4/15/2005	76.0	53.0	0.00	84	19
4/16/2005	76.0	51.0	0.00	95	21
4/17/2005	81.0	55.0	0.00	98	18
4/18/2005	79.0	62.0	0.00	88	22
4/19/2005	77.0	60.0	0.00	94	29
4/20/2005	78.0	64.0	0.01	97	33
4/21/2005	81.0	67.0	0.01	96	32
4/22/2005	84.0	67.0	0.00	96	27
4/23/2005	85.0	54.0	0.07	93	30
4/24/2005	73.0	46.0	0.00	95	17
4/25/2005	74.0	58.0	0.02	96	17
4/26/2005	68.0	60.0	0.34	98	51
4/27/2005	76.0	50.0	0.00	84	18
4/28/2005	85.0	54.0	0.00	93	15
4/29/2005	86.0	67.0	0.00	92	17
4/30/2005	77.0	44.0	0.00	91	83
5/1/2005	68.0	47.0	0.00	93	28
5/2/2005	74.0	50.0	0.00	82	19
5/3/2005	77.0	54.0	0.00	80	19
5/4/2005	78.0	57.0	0.18	89	19
5/5/2005	76.0	54.0	0.00	84	19
5/6/2005	80.0	59.0	0.00	92	18
5/7/2005	83.0	59.0	0.00	98	18
5/8/2005	81.0	69.0	0.00	80	28
5/9/2005	73.0	60.0	3.70	98	49
5/10/2005	80.0	63.0	0.01	98	34
5/11/2005	85.0	69.0	0.00	94	30
5/12/2005	84.0	69.0	0.00	94	25
5/13/2005	83.0	68.0	0.00	94	28
5/14/2005	83.0	66.0	0.00	94	20
5/15/2005	84.0	65.0	0.00	80	18
5/16/2005	85.0	65.0	0.00	86	17
5/17/2005	80.0	60.0	0.52	92	27
5/18/2005	82.0	63.0	0.03	95	24
5/19/2005	86.0	66.0	0.00	94	25
5/20/2005	87.0	68.0	0.00	94	21
5/21/2005	89.0	69.0	0.00	88	17
5/22/2005	94.0	70.0	0.00	87	18
5/23/2005	93.0	72.0	0.00	85	18
5/24/2005	91.0	67.0	0.00	89	19

5/25/2005	90.0	70.0	0.00	88	20
5/26/2005	92.0	71.0	0.00	88	17
5/27/2005	85.0	68.0	1.55	93	31
5/28/2005	88.0	69.0	0.00	91	24
5/29/2005	86.0	66.0	0.70	92	23
5/30/2005	84.5	67.5	2.47	92	36
5/31/2005	83.0	69.0	0.01	94	30
6/1/2005	88.0	65.0	0.34	93	21
6/2/2005	84.0	65.0	0.00	91	26
6/3/2005	89.0	70.0	0.00	89	26
6/4/2005	87.0	73.0	0.00	92	30
6/5/2005	89.0	74.0	0.00	90	28
6/6/2005	91.0	74.0	0.00	92	27
6/7/2005	91.0	75.0	0.00	90	26
6/8/2005	90.0	75.0	0.00	89	26
6/9/2005	90.0	73.0	0.00	92	27
6/10/2005	89.0	71.0	0.00	92	25
6/11/2005	91.0	72.0	0.00	89	20
6/12/2005	92.0	72.0	0.00	89	17
6/13/2005	92.0	72.0	0.00	88	20
6/14/2005	91.0	73.0	0.00	93	26
6/15/2005	96.0	75.0	0.00	92	16
6/16/2005	95.0	73.0	0.00	82	17
6/17/2005	94.0	72.0	0.00	87	19
6/18/2005	94.0	72.0	0.00	88	17
6/19/2005	95.0	74.0	0.00	87	16
6/20/2005	94.0	70.0	0.00	89	16
6/21/2005	92.0	68.0	0.00	87	16
6/22/2005	93.0	69.0	0.00	86	15
6/23/2005	94.0	70.0	0.00	84	15
6/24/2005	94.0	68.0	0.00	85	15
6/25/2005	94.0	69.0	0.00	81	15
6/26/2005	95.0	71.0	0.00	87	15
6/27/2005	94.0	70.0	0.00	86	16
6/28/2005	94.0	70.0	0.00	88	17
6/29/2005	95.0	70.0	0.00	89	14
6/30/2005	96.0	73.0	0.00	88	16
7/1/2005	97.0	75.0	0.00	84	16
7/2/2005	98.0	75.0	0.00	86	15
7/3/2005	98.0	75.0	0.00	88	15
7/4/2005	97.0	75.0	0.00	85	16
7/5/2005	98.0	72.0	0.00	88	17
7/6/2005	99.0	74.0	0.00	89	14
7/7/2005	102.0	76.0	0.12	80	14
7/8/2005	98.0	69.0	0.55	88	15

7/9/2005	92.0	71.0	0.00	85	18
7/10/2005	90.0	71.0	0.00	83	22
7/11/2005	96.0	73.0	0.00	82	16
7/12/2005	95.0	73.0	0.00	85	16
7/13/2005	96.0	75.0	0.00	88	16
7/14/2005	97.0	74.0	0.00	90	16
7/15/2005	98.0	71.0	1.55	91	15
7/16/2005	98.0	71.0	2.06	91	48
7/17/2005	85.0	73.0	0.48	91	35
7/18/2005	90.0	75.0	0.26	91	27
7/19/2005	92.0	73.0	0.01	90	23
7/20/2005	93.0	75.0	0.00	90	25
7/21/2005	92.0	74.0	0.05	91	24
7/22/2005	91.0	74.0	0.13	91	27
7/23/2005	95.0	73.0	0.04	88	16
7/24/2005	94.0	74.0	0.00	88	18
7/25/2005	93.0	75.0	1.24	88	20
7/26/2005	93.0	73.0	0.00	88	19
7/27/2005	94.0	72.0	0.00	88	18
7/28/2005	92.0	72.0	0.00	88	18
7/29/2005	95.0	73.0	0.00	89	18
7/30/2005	94.0	75.0	0.06	89	26
7/31/2005	92.0	69.0	0.00	83	16
8/1/2005	105.0	71.0	0.00	84	16
8/2/2005	96.0	73.0	0.00	84	15
8/3/2005	95.0	74.0	0.00	85	17
8/4/2005	94.0	74.0	0.00	85	16
8/5/2005	94.0	72.0	0.00	85	17
8/6/2005	91.0	71.0	0.07	86	24
8/7/2005	96.0	74.0	0.00	84	16
8/8/2005	94.0	73.0	0.00	84	16
8/9/2005	96.0	74.0	0.02	84	16
8/10/2005	94.0	73.0	0.00	85	17
8/11/2005	97.0	71.0	0.00	85	16
8/12/2005	95.0	73.0	0.00	87	17
8/13/2005	96.0	74.0	0.01	87	17
8/14/2005	96.0	75.0	0.00	86	17
8/15/2005	93.0	75.0	0.15	88	27
8/16/2005	95.0	74.0	0.05	88	17
8/17/2005	91.0	72.0	0.36	88	27
8/18/2005	96.0	72.0	0.00	88	16
8/19/2005	96.0	73.0	0.00	87	17
8/20/2005	96.0	72.0	0.00	88	16
8/21/2005	97.0	71.0	0.00	88	15
8/22/2005	98.0	75.0	0.00	88	14

8/23/2005	98.0	75.0	0.00	88	15
8/24/2005	98.0	74.0	0.00	86	15
8/25/2005	99.0	74.0	0.00	86	15
8/26/2005	95.0	75.0	0.00	86	17
8/27/2005	97.0	74.0	0.00	86	16
8/28/2005	97.0	72.0	1.73	91	14
8/29/2005	92.0	73.0	0.00	87	22
8/30/2005	93.0	72.0	0.00	83	17
8/31/2005	96.0	73.0	0.00	83	15
9/1/2005	97.0	73.0	0.00	84	14
9/2/2005	95.0	73.0	0.00	86	16
9/3/2005	90.0	72.0	0.13	86	23
9/4/2005	90.0	73.0	0.00	87	24
9/5/2005	95.0	67.0	0.00	82	14
9/6/2005	96.0	69.0	0.00	83	14
9/7/2005	93.0	67.0	0.00	83	16
9/8/2005	91.0	66.0	0.00	78	15
9/9/2005	93.0	67.0	0.00	82	16
9/10/2005	92.0	70.0	0.00	83	15
9/11/2005	87.0	74.0	0.08	89	35
9/12/2005	86.0	72.0	0.00	85	22
9/13/2005	87.0	72.0	0.23	89	35
9/14/2005	93.0	72.0	0.03	89	23
9/15/2005	95.0	73.0	0.00	89	18
9/16/2005	96.0	74.0	0.00	88	18
9/17/2005	95.0	73.0	0.00	88	17
9/18/2005	96.0	72.0	0.00	89	16
9/19/2005	97.0	71.0	0.00	90	15
9/20/2005	94.0	70.0	0.00	89	15
9/21/2005	97.0	72.0	0.00	87	14
9/22/2005	99.0	72.0	0.00	85	13
9/23/2005	101.0	71.0	0.00	96	13
9/24/2005	96.0	78.0	0.00	96	14
9/25/2005	96.0	73.0	0.00	82	14
9/26/2005	104.0	76.0	0.00	85	12
9/27/2005	104.0	75.0	0.00	85	13
9/28/2005	104.0	76.0	0.00	84	12
9/29/2005	102.0	75.0	0.00	86	14
9/30/2005	89.0	69.0	0.00	88	19

APPENDIX C

CLIMATIC CONDITIONS AT TEXAS AGRICULTURAL RESEARCH AND EDUCATION CENTER NEAR EAGLE LAKE, TX.

2006 GROWING SEASON

2006

Date	Air Temperature (°F)		Precipitation (in)	Relative Humidity (%)	
	Max	Min		Max	Min
3/1/2006	74.0	50.0	0.00	92	23
3/2/2006	80.0	57.0	0.00	92	19
3/3/2006	81.0	56.0	0.00	93	20
3/4/2006	75.0	46.0	0.00	94	18
3/5/2006	72.0	50.0	0.00	90	22
3/6/2006	79.0	49.0	0.00	90	31
3/7/2006	81.0	64.0	0.00	91	20
3/8/2006	79.0	63.0	0.00	90	25
3/9/2006	80.0	64.0	0.00	86	23
3/10/2006	82.0	48.0	0.00	91	15
3/11/2006	84.0	56.0	0.00	93	25
3/12/2006	85.0	70.0	0.00	78	24
3/13/2006	85.0	70.0	0.02	78	27
3/14/2006	74.0	47.0	0.00	78	17
3/15/2006	73.0	43.0	0.00	81	17
3/16/2006	69.0	48.0	0.00	83	22
3/17/2006	84.0	63.0	0.00	87	25
3/18/2006	77.0	65.0	0.00	88	25
3/19/2006	75.0	70.0	0.15	90	35
3/20/2006	76.0	61.0	0.27	91	35
3/21/2006	76.0	44.0	0.05	91	16
3/22/2006	66.0	41.0	0.00	88	19
3/23/2006	58.0	42.0	0.02	85	25
3/24/2006	52.0	31.0	0.00	83	25
3/25/2006	60.0	33.0	0.00	80	20
3/26/2006	69.0	38.0	0.00	77	18
3/27/2006	73.0	54.0	0.00	82	17
3/28/2006	72.0	58.0	0.01	86	37
3/29/2006	66.0	54.0	0.67	92	42
3/30/2006	74.0	59.0	0.40	92	47
3/31/2006	78.0	66.0	0.00	92	31
4/1/2006	82.0	70.0	0.02	89	29
4/2/2006	83.0	70.0	0.00	88	25
4/3/2006	83.0	67.0	0.00	88	25
4/4/2006	86.0	66.0	0.00	88	20
4/5/2006	83.0	65.0	0.00	90	22
4/6/2006	84.0	65.0	0.00	90	19
4/7/2006	80.0	65.0	0.00	87	29
4/8/2006	87.0	52.0	0.00	90	20
4/9/2006	73.0	50.0	0.00	90	19

4/10/2006	80.0	47.0	0.00	86	16
4/11/2006	80.0	49.0	0.00	91	16
4/12/2006	80.0	58.0	0.00	90	19
4/13/2006	80.0	62.0	0.00	91	30
4/14/2006	84.0	59.0	0.00	93	17
4/15/2006	84.0	62.0	0.00	91	18
4/16/2006	85.0	63.0	0.00	90	20
4/17/2006	88.0	69.0	0.00	88	18
4/18/2006	94.0	68.0	0.00	86	17
4/19/2006	91.0	67.0	0.00	88	17
4/20/2006	90.0	69.0	0.00	89	18
4/21/2006	88.7	66.7	1.17	92	18
4/22/2006	87.3	64.3	0.00	92	21
4/23/2006	86.0	62.0	0.00	91	17
4/24/2006	86.0	65.0	0.00	92	21
4/25/2006	85.0	70.0	0.00	90	27
4/26/2006	90.0	55.0	0.00	87	19
4/27/2006	74.0	55.0	0.00	91	25
4/28/2006	79.0	56.0	0.00	90	19
4/29/2006	86.0	64.0	0.20	82	25
4/30/2006	83.0	57.0	0.01	82	17
5/1/2006	87.0	59.0	0.00	80	14
5/2/2006	90.0	60.0	0.00	89	17
5/3/2006	89.0	70.0	0.08	89	18
5/4/2006	90.0	67.0	0.00	88	16
5/5/2006	91.0	66.0	0.09	88	16
5/6/2006	89.0	62.0	1.09	92	16
5/7/2006	84.0	65.0	0.03	85	77
5/8/2006	83.0	66.0	0.00	76	31
5/9/2006	87.0	69.0	0.00	88	29
5/10/2006	90.0	75.0	0.00	87	26
5/11/2006	92.0	56.0	0.06	78	20
5/12/2006	81.0	53.0	0.00	81	15
5/13/2006	86.0	54.0	0.00	84	16
5/14/2006	90.0	67.0	0.00	83	16
5/15/2006	88.0	63.0	0.00	88	22
5/16/2006	77.0	52.0	0.00	87	18
5/17/2006	83.0	55.0	0.00	86	17
5/18/2006	87.0	58.0	0.00	85	16
5/19/2006	93.0	62.0	0.00	84	14
5/20/2006	94.0	65.0	0.00	87	14
5/21/2006	90.0	63.0	0.00	88	16
5/22/2006	91.0	67.0	0.00	91	15
5/23/2006	91.0	69.0	0.00	91	16
5/24/2006	91.0	68.0	0.00	90	16

5/25/2006	94.0	69.0	0.00	90	15
5/26/2006	94.0	71.0	0.00	85	15
5/27/2006	93.0	72.0	0.00	88	16
5/28/2006	93.0	71.0	0.33	84	17
5/29/2006	83.0	70.0	0.12	89	20
5/30/2006	87.0	71.0	0.70	85	29
5/31/2006	84.0	67.0	0.53	89	28
6/1/2006	75.0	68.0	0.12	89	61
6/2/2006	85.0	69.0	0.02	89	21
6/3/2006	89.0	69.0	0.00	86	16
6/4/2006	91.0	67.0	0.00	87	16
6/5/2006	91.0	70.0	0.00	85	15
6/6/2006	90.0	68.0	0.00	85	17
6/7/2006	91.0	68.0	0.00	87	17
6/8/2006	92.0	71.0	0.00	83	16
6/9/2006	93.0	70.0	0.00	85	15
6/10/2006	95.0	69.0	0.00	86	15
6/11/2006	94.0	68.0	0.00	88	14
6/12/2006	93.0	62.0	0.00	89	15
6/13/2006	96.0	65.0	0.00	90	14
6/14/2006	102.0	72.0	0.02	89	13
6/15/2006	93.0	67.0	0.00	88	15
6/16/2006	95.0	71.0	0.00	87	15
6/17/2006	91.0	75.0	0.39	88	22
6/18/2006	87.0	70.0	1.52	89	33
6/19/2006	91.0	74.0	0.35	88	19
6/20/2006	88.0	72.0	0.08	87	28
6/21/2006	78.0	71.0	1.24	89	47
6/22/2006	90.0	72.0	0.00	89	25
6/23/2006	92.0	71.0	0.00	90	19
6/24/2006	93.0	72.0	0.00	91	15
6/25/2006	90.0	74.0	0.00	82	18
6/26/2006	94.0	71.0	0.00	82	15
6/27/2006	92.0	65.0	0.00	81	15
6/28/2006	89.0	65.0	0.00	81	16
6/29/2006	91.0	66.0	0.00	80	15
6/30/2006	90.0	69.0	0.00	80	16
7/1/2006	91.0	71.0	0.00	85	17
7/2/2006	88.0	70.0	1.05	91	26
7/3/2006	84.0	71.0	0.00	91	30
7/4/2006	83.0	73.0	0.00	89	36
7/5/2006	88.0	71.0	3.95	92	33
7/6/2006	85.0	72.0	0.00	92	33
7/7/2006	87.0	73.0	0.11	91	28
7/8/2006	88.0	74.0	0.00	89	28

7/9/2006	91.0	74.0	0.00	90	29
7/10/2006	86.0	75.0	0.52	89	35
7/11/2006	91.0	74.0	0.00	88	22
7/12/2006	92.0	74.0	0.00	87	23
7/13/2006	92.5	74.0	0.00	87	20
7/14/2006	93.0	74.0	0.00	87	17
7/15/2006	92.0	72.0	0.00	84	20
7/16/2006	94.0	75.0	0.00	84	16
7/17/2006	94.0	74.0	0.00	83	16
7/18/2006	95.0	75.0	0.00	82	17
7/19/2006	92.0	73.0	0.00	87	20
7/20/2006	94.0	74.0	0.00	87	15
7/21/2006	92.0	73.0	0.00	87	17
7/22/2006	96.0	73.0	0.00	87	15
7/23/2006	97.0	73.0	0.08	88	15
7/24/2006	94.0	72.0	0.00	87	17
7/25/2006	87.0	72.0	2.66	89	36
7/26/2006	82.0	71.0	1.52	90	37
7/27/2006	81.0	73.0	0.36	91	66
7/28/2006	81.0	73.0	0.36	91	66
7/29/2006	91.0	75.0	0.00	91	22
7/30/2006	93.0	73.0	0.00	91	23
7/31/2006	93.0	75.0	0.00	87	17
8/1/2006	92.0	73.0	0.00	88	22
8/2/2006	92.0	73.0	0.00	89	18
8/3/2006	90.0	72.0	0.76	87	28
8/4/2006	94.0	73.0	0.00	89	17
8/5/2006	94.0	74.0	0.00	89	16
8/6/2006	95.0	74.0	0.00	84	15
8/7/2006	91.0	76.0	0.03	86	18
8/8/2006	92.0	73.0	0.10	88	21
8/9/2006	89.0	73.0	0.00	89	26
8/10/2006	95.0	73.0	0.00	89	16
8/11/2006	94.0	73.0	0.00	86	16
8/12/2006	96.0	72.0	0.00	89	16
8/13/2006	94.0	73.0	0.00	87	16
8/14/2006	94.0	73.0	0.00	87	15
8/15/2006	96.0	73.0	0.00	87	16
8/16/2006	97.0	73.0	0.00	89	15
8/17/2006	98.0	74.0	0.00	89	14
8/18/2006	99.0	76.0	0.00	90	14
8/19/2006	97.0	74.0	0.02	90	14
8/20/2006	88.0	73.0	0.01	90	29
8/21/2006	96.0	73.0	0.00	87	15
8/22/2006	96.0	72.0	0.00	88	15

8/23/2006	95.0	73.0	0.13	87	16
8/24/2006	94.0	73.0	0.00	86	16
8/25/2006	96.0	75.0	0.00	87	15
8/26/2006	98.0	75.0	0.00	86	14
8/27/2006	96.0	75.0	0.10	87	16
8/28/2006	92.0	75.0	0.03	86	22
8/29/2006	97.0	74.0	0.00	87	15
8/30/2006	96.0	73.0	0.00	83	15
8/31/2006	93.0	67.0	0.00	83	15
9/1/2006	96.0	67.0	0.00	83	14
9/2/2006	98.0	70.0	0.02	85	14
9/3/2006	95.0	71.0	0.04	83	15
9/4/2006	94.0	69.0	0.00	84	15
9/5/2006	93.0	71.0	0.02	85	16
9/6/2006	78.0	65.0	0.09	86	32
9/7/2006	92.0	61.0	0.00	82	15
9/8/2006	94.0	61.0	0.00	83	14
9/9/2006	91.0	68.0	0.48	89	16
9/10/2006	79.0	70.0	0.04	91	52
9/11/2006	92.0	72.0	0.00	90	40
9/12/2006	87.0	72.0	0.10	89	27
9/13/2006	85.0	70.0	0.00	89	27
9/14/2006	92.0	65.0	0.00	90	15
9/15/2006	94.0	68.0	0.00	91	15
9/16/2006	95.0	70.0	0.00	89	15
9/17/2006	96.0	72.0	0.00	88	16
9/18/2006	95.0	71.0	0.80	86	16
9/19/2006	82.0	63.0	0.04	89	37
9/20/2006	87.0	58.0	0.00	86	16
9/21/2006	88.0	58.0	0.00	78	16
9/22/2006	94.0	64.0	0.00	81	17
9/23/2006	93.0	78.0	0.00	82	20
9/24/2006	95.0	70.0	1.62	89	18
9/25/2006	76.0	58.0	0.00	88	20
9/26/2006	80.0	57.0	0.00	87	18
9/27/2006	85.0	57.0	0.00	86	16
9/28/2006	88.0	61.0	0.00	85	17
9/29/2006	83.0	60.0	0.00	88	22
9/30/2006	90.0	63.0	0.00	89	17

APPENDIX D

SOURCES OF MATERIALS

SOURCES OF MATERIALS

Chapter II

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

[2] Silicon based surfactant, Kinetic®, is a blend of polyalkyleneoxide modified polydimethylsiloxane and polyoxypropylene-polyoxyethylene block co-polymers. Helena Chemical Company, 6075 Poplar Avenue, Suite 500, Memphis, TN 38119.

[3] Kubota Skyrod RX 1450, Kubota Manufacturing of America Corporation, 2715 Ramsey Road, Gainesville, GA 30501.

Chapter III

[4] Silicon based surfactant, Kinetic®, is a blend of polyalkyleneoxide modified polydimethylsiloxane and polyoxypropylene-polyoxyethylene block co-polymers. Helena Chemical Company, 6075 Poplar Avenue, Suite 500, Memphis, TN 38119.

[5] Dyne-A-Pak®, non-ionic spray adjuvant and deposition aide, proprietary blend of alkanolamides, alkanoates, trisiloxane, and carbamides. Helena Chemical Company, Collierville, TN 38017.

[6] Crop oil concentrate, Agri-Dex®, is a nonionic spray adjuvant consisting of a blend of heavy paraffin based petroleum oil, ployol fatty acid esters, and

polyethoxylated derivatives. Helena Chemical Company, 6075 Poplar Avenue, Suite 500, Memphis, TN 38119.

[7] Kubota Skyrod RX 1450, Kubota Manufacturing of America Corporation, 2715 Ramsey Road, Gainesville, GA 30501.

Chapter IV

[8] MetroMix 200. The Scotts Company. 14111 Scottslawn Road. Marysville, OH 43041.

[9] Low pressure sodium lamps, Model No. N081 470 00053, 135 W, North American Philips Lighting Corporation, Bank Street, Hightstown, NJ 08520.

[10] VHO fluorescent bulbs, Model No. F22T12/CW/VHO, North American Philips Lighting Corporation, Bank Street, Hightstown, NJ 08520.

[11] Clear incandescent bulbs, clear, 60 W, Osram Sylvania, 100 Endicott Street, Danvers, MA 01923.

[12] 8002 flat fan nozzle, TeeJet Spraying Systems Co.; Wheaton, IL 60189.

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

[14] Peter's General Purpose 20-20-20. The Scotts Company. 14111 Scottslawn Road, Marysville, OH 43041.

[15] Carbon-14 cocktail, R.J. Harvey Instrument Company, 123 Patterson Street, Hillsdale, NJ 07642.

[16] Packard Oxidizer 306, Packard Instruments Company, 2200 Warrenville Road, Downers Grove, IL 60515.

[17] Tri-carb 2500TR Liquid Scintillation Analyzer, Packard Bio-Science Company, 800 Research Parkway, Downers Grove, IL 60515.

VITA

Samuel Duane Willingham was born in Gainesville, Florida and attended High School in Alachua, Florida graduating from Santa Fe High in June 1992. He then attended Santa Fe Community College part-time while working full-time in banking. Sam received his Associate of Arts degree in 1999. That same year he started at the University of Florida where he graduated with a Bachelor of Science degree in Agronomy in May 2002. That summer he began his master's degree program at the University of Florida specializing in weed management in peanuts. Research focused on reduced herbicide inputs in twin and single-row peanut. In May 2004, he graduated with a Master of Science degree then moved to Texas to attend Texas A&M University to pursue a Doctor of Philosophy degree in Agronomy specializing in weed management in rice. In May of 2008, Sam was awarded a Doctor of Philosophy degree in Agronomy.

Sam is a member of several organizations including Southern Weed Science Society, Weed Science Society of America, American Society of Agronomy, and Texas Plant Protection Association. Sam has authored 5 refereed journal articles, 20 published abstracts, co-authored 5 published abstracts, and presented 8 presentations by invitation. Sam currently can be reached at Texas A&M University, Department of Soil and Crop Sciences, 370 Olsen Blvd., College Station, TX 77843-2474.