2010

Texasweed (Caperonia palustris (L.) St. Hil.) interference and management in drill-seeded rice

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Recommended Citation
Godara, Rakesh K., "Texasweed (Caperonia palustris (L.) St. Hil.) interference and management in drill-seeded rice" (2010). *LSU Doctoral Dissertations*. 2000.
https://digitalcommons.lsu.edu/gradschool_dissertations/2000

TEXASWEED [*CAPERONIA PALUSTRIS* (L.) ST. HIL.] INTERFERENCE AND MANAGEMENT IN DRILL-SEEDED RICE

A Dissertation

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

in

The School of Plant, Environmental, and Soil Sciences

by
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December 2010

Acknowledgements

I would like to thank God for providing me the gift of my family, friends and the means to pursue my goals in life.

Thanks to my parents, Savitri Devi and Mahabir Singh Godara, for all their love and support. Your support throughout my education is what has contributed to my success and all that I have accomplished.

To my wife Anu, thanks for your love and support. Thanks for never complaining about the many lonely evenings and weekends while I was bound to computer writing or in our study room reading and researching. We have been through a lot in just two short years of our marriage. I truly appreciate your ability to tolerate me during these times.

I owe my major professor, Dr. Bill Williams, a tremendous amount of gratitude. Not only has he been a wonderful mentor but a great friend. He challenged me to do my best and provided unparalleled opportunities for learning, thinking, research, and personal growth. I deeply appreciate the belief and confidence that he had in my abilities to complete this work. Thank you Dr. Bill, for all that you have done for me!

I also want to thank Dr. Eric Webster for being a part of my graduate committee and providing me with the office space and resources during the course of my stay in Baton Rouge. I am grateful to the other members of my graduate committee, Dr. Jim Griffin, Dr. Donnie Miller, Dr. James Geaghan, and Dr. Quang Cao. The time, education, and guidance I have received from you all have been a great resource for me while completing this degree program at the Louisiana State University.

Thanks to Ann Burns, Suzanne Laird, and many student workers who helped me in the tedious work of managing my experiments. I also thank the administration and staff of Northeast Research Station near Saint Joseph, La. for providing me an accommodation and the help with my field experiments.

I would like to thank the Louisiana State University AgCenter, the School of Plant, Environmental, and Soil Sciences, and the Louisiana Rice Research Board for the opportunity, support, and financial funding needed for this research.

I would also like to express my appreciation for Dr. Justin Hensley, Dr. Sunny Bottoms, Dr. Charanjit Kahlon, Dr. Ashok Badigannavar and Joey Boudreaux for their friendship and help. You helped make my time at Louisiana State University an enjoyable experience.

To my friends Dr. Bhagat Singh, Dr. Bhagwat Singh Rathore, Sant Kumar, Dr. Mayank Malik, Dr. Prashant Jha, Dr. Vinod Shivrain, and Dr. Sanjeev Bangarwa, it was your guidance, support, and at times the constructive criticism that has helped me become a better person and researcher. You all have lived up to the saying ‘books and friends should be a few but good’.

Table of Contents

Abstract

Field research was conducted from 2006 to 2009 to study Texasweed [Caperonia palustris (L.) St. Hil.] interference and management in Cocodrie rice. Texasweed interference at 10 plants/m^2 caused 24 to 31% rice yield reduction. The maximum possible yield loss was estimated to be 81%. Rice yield reduction was primarily due to a reduction in culms/m^2 and filled grains per panicle. For maximum yield, Texasweed must be removed by two weeks after emergence and managed until permanent flood establishment.

Shade had no effect on Texasweed emergence but significantly reduced growth and reproduction. At 100 days after emergence, 50, 70, and 90% shade reduced dry matter per plant by 31, 47, and 90%, respectively. Texasweed height increased with increasing shade up to 70% and then decreased. After 28 DAI, Texasweed height in 70% shade increased 15 to 21% compared with 0% shade. Texasweed seemed to mitigate the adverse effect of shade on growth by increasing specific leaf area and leaf biomass.

In a flood depth study, Texasweed plants were able to survive and produce seeds in flood depths up to 30 cm; however, growth and fruit production were reduced. A 76 and 41% reduction in total dry matter per plant was recorded for Texasweed flooded at two- to three-leaf and four- to five-leaf stage, respectively. Increasing flood depths resulted in an increase in plant height and greater biomass allocation to the stem. Texasweed plants produced adventitious roots and a thick spongy tissue, secondary aerenchyma, in the submerged roots and stem, which may play a role in its survival under flooded conditions.

For Texasweed control, bensulfuron-methyl interacted synergistically with both penoxsulam and bispyribac-sodium. Bensulfuron-methyl, therefore, can be mixed with either penoxsulam or bispyribac-sodium to improve Texasweed control. V-10142 provided excellent PRE and EPOST activity on Texasweed. V-10142 at 224 g ai/ha by itself, applied to four- to five- leaf Texasweed, was not effective but improved Texasweed control when mixed with bispyribac-sodium at 29 g ai/ha or penoxsulam at 40 g ai/ha.

Chapter 1

Introduction

Rice (*Oryza sativa* L.) is one of the most important crops in the world. It is the predominant staple food for 17 countries in Asia and the Pacific, nine countries in North and South America and eight countries in Africa, and provides 20% of the world's dietary energy supply (Anonymous 2004). In 2009, worldwide rice acreage was approximately 158 million hectares, with a total production of about 670 million tons of rough rice (Anonymous 2010a). The United States produces about 10 million metric tons of rice every year, with Arkansas, California, Louisiana, Mississippi, Missouri and Texas as the major rice producing states. Besides meeting the domestic demand the United States also exports 40 to 50% of its rice to various rice consuming nations around the world. Total US rice exports were approximately 4.35 million metric tons in 2009. Among the rice growing states in the USA, Louisiana is ranked third in area planted and production. Louisiana produced 1.326 million tons of rice on 187.8 thousand hectares in 2009 (Anonymous 2010a)

Almost all of the rice cultivated in the USA is planted by direct-seeding method (Linscombe 1999; Slaton and Cartwright 2010). Direct-seeding of rice can be accomplished by broadcasting dry or pre-sprouted seed into shallow standing water, water-seeding, by broadcasting dry seed into a drained or dry field, dry broadcasting, or by drilling in rows spaced 18 to 25 cm apart into prepared seedbeds, drill-seeding (Linscombe 1999). Water-seeding of rice is a management tool to manage red rice (Oryza sativa L.)(Avila et al. 2005), which is the primary reason for the popularity of this system in Louisiana (Linscombe et al. 1999). Drill-seeding provides better growing conditions for young rice plants; however, the same conditions are also favorable to many weeds which can be very competitive (Estorninos et al. 2005; Ottis et al. 2005; Ottis and Talbert 2007; Smith 1968; 1988). Early season weed control is an important management problem on which the success of drill-seeded rice depends.

Weed communities in rice are dominated by grassy weed species (Fischer et al. 2004). Holm et al. (1977) and Valverde et al. (2001) reported barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] and junglerice [*Echinochloa colona* (L.) Link.] as the most important weeds of rice worldwide. *Echinochloa* spp. are also the most common weeds in Louisiana rice (Webster 2004). Stauber et al. (1991) reported 301 and 257 kg/ha yield loss in Newbonnet and Lemont rice varieties, respectively, per barnyardgrass plant as density increased from one to 40 plants per square meter. Red rice, a wild relative of cultivated rice, is another important weed in the rice production systems in the United States. Red rice even at low densities can cause severe growth and yield reduction in rice. A yield loss of 178 and 272 kg/ha per unit increase in red rice density was reported in the older rice varieties ‘Newbonnet’ and ‘Lemont’, respectively (Estorninos et al. 2005; Ottis et al. 2005). In newer rice varieties, ‘CL 161’, ‘XL8’, and ‘Cocodrie’ rice grain yield was reduced between 100 and 755 kg/ha (Kwon et al. 1991; Ottis et al. 2005).

Broadleaf weeds and sedges can also cause yield loss in rice (Caton et al. 1997; Smith 1968, 1984; Zhang et al. 2004). Many broadleaf weeds like alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.], eclipta [*Eclipta prostrata* (L.) L.], hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh], purple ammannia (*Ammannia coccinea* Rottb.), and spreading dayflower (*Commelina diffusa* Burm. f.) are common in the rice fields (Barret and Seaman 1980). Hemp sesbania and morningglory (*Ipomoea* spp.) can reduce rice yield and harvest efficiency, and impair crop quality (Turner et al. 1990). Zhang et al. (2004) reported 45% rice yield loss due to alligatorweed interference. Smith (1984) reported 18% yield loss in rice due to season long spreading dayflower interference at 22 plants/m^2 per. Caton et al. (1997) reported

Ammannia spp. to be widespread and competitive in California rice fields. They also reported 39% rice yield reduction due to purple ammannia at 100 plants per square meter in a glasshouse study.

Texasweed [*Caperonia palustris* (L.) St. Hil.], also known as sacatrapo (USDA 2007) is an annual broadleaf plant belonging to the Euphorbiaceae family (USDA 2007). It has smooth cotyledons and coarsely pubescent stems and petioles. The leaves are 3 to 15 cm long, alternate, broadly lanceolate, and serrated on the margins (Bryson and DeFelice 2009). The seeds are dark brown, 2.5 mm in diameter, and minutely pitted. The plant can attain a height of up to three meters. Texasweed is often mistaken for Mexicanweed [*Caperonia castenifolia* (L.) St. Hil.], which is a perennial plant with glabrous stems. Texasweed is described as native to the United States in the invasive and noxious weeds list of the NRCS, USDA (USDA 2007). It has also been described as an invasive (Anonymous 2007), non-native naturalized (Gann et al. 2007) species in the southern United States, and native to warmer parts of South America south of Paraguay (Godfrey and Wooten 1981). Texasweed has existed in the Unites States as a wetland plant (Godfrey and Wooten 1981). It has not been a major problem in crop production, but in the present decade, it has become increasingly common in rice, cotton, and soybean fields in the states of Texas, Louisiana, Mississippi, and Arkansas (Koger et al. 2004; Poston et al. 2007).

Gianessi et al. (2002) reported Texasweed as the most troublesome broadleaf weed in Texas and Louisiana rice production systems. Overall it was ranked 3rd and 5th most troublesome weed in the rice production systems of the two states, respectively. Bennett (2003) also reported Texasweed as an emerging problem in Arkansas rice fields. It is reported to reduce harvest efficiency of combine harvesters particularly in rice (Bennett 2003). Besides reducing the harvest efficiency, the dark brown or grey colored Texasweed seeds are also a great concern to the rice growers. The seeds can be an important source of contamination in rice and result in a lower price (Bill Williams[1], Personal communication). The problem of Texasweed seeds in rice seems similar to red rice, which if present in significant amount reduces the market value of rice (Smith 1979).

Weed management programs in rice, like any other crop, involve a complex integration of various cultural, mechanical, biological, and chemical of weed control. Cultural practices like tillage, crop rotation, variety selection, rice seeding rate, and row spacing and orientation are generally based on agronomic considerations, but have a bearing on crop-weed interaction, and can be manipulated to tilt the crop-weed interaction in the favor of crops (Roa 2000). Moreover, herbicide resistance (Boerboom 1999; Chhokar and Sharma 2008; Roush et al. 1990) and increasing interest in organic agriculture calls for alternate methods of weed management. Successful utilization of alternate methods of weed control requires an understanding of the principles of weed biology and ecology (Maxwell and Donovan 2007).

In many crops, early canopy closure achieved using competitive crop cultivars and/or management practices is used as a strategy to shade weeds and tilt the crop-weed interaction in the favor of crop. Crops, however, differ in their competitive ability; crops with rapid early season growth are more competitive than those with a long period of slow growth early in the season (Keely and Thullen 1978). The relative time of emergence and rate of canopy formation are the important factors in determining the competitiveness between the crop and weed. The time and rate of canopy closure depends on the crop and the row spacing (Caton et al. 2002; Murdock et al. 1986). Murdock et al. (1986) reported that regardless of row spacing and cultivar, photosynthetically active radiation (PAR) at soil surface near a soybean plant was reduced by 50, 70, and 90% at 23, 29, and 40 days after planting, respectively. The days required to reduce PAR by these percentages at a point midway between two rows was dependent on the row spacing; the estimated values 90% PAR reduction in 61 cm and 91 cm row spacing were 53 and 63 days after planting, respectively. Thus row spacing affects the time to beginning of the canopy closure, i.e. the time when it starts to shade the middle of the rows. Once a canopy starts to close, regardless of the row spacing, the available PAR reduces from 50 to 90% in about 10 to 15 days.

Dingkuhn et al. (1999) reported that 30 and 45 days after planting (DAP) 'Bouke 189', a semi-dwarf indica type rice cultivar, caused 16 and 54% reduction in the diffused PAR reaching the soil surface. In comparision, the reduction in PAR by 'Moroberekan', a tall japonica type cultivar, was 18 and 56%, respectively. No rice cultivar intercepted more than 20% of the PAR at 30 DAP, and PAR availability increased sharply towards the top of the canopy. At 64 DAP, the short-statured and erect leaved 'Bouake 189' caused only 25% PAR reduction at a point 40 cm above the ground; the reduction caused by other cultivars ranged between 50 and 70%.

The weed suppressing effect of a crop canopy is a result of shading, which can reduce weed emergence and growth (Caton et al. 1997; Caton et al. 2001; Gibson et al. 2001; Jha and Norsworthy 2009). Plants differ in their photosynthetic efficiency and response to shade. Some plant species can escape the adverse effects of shade by increasing their height and shoot/root partitioning (Caton et al. 1997) and/or by increasing leaf area in proportion to the total plant tissue (Patterson 1979).

Texasweed has been observed thriving under a thick hemp sesbania canopy in the rice paddies at Louisiana State University AgCenter Northeast Research Station near St. Joseph, Louisiana (Bill Williams[1], personal communication). Hemp sesbania forms a very dense canopy and severely reduces the growth of rice crop and other plant species growing under it (Smith 1968). Texasweed's ability to grow and reproduce under low light conditions under can have implications on its management in crops which rely on a crop canopy cover for mid- and late-season weed control.

Establishment of permanent flood is an important cultural practice for weed management in rice culture (Bouman et al. 2007; Mortimer et al. 1999; Williams et al. 2001). Flooding can affect both weed emergence and growth. Smith and Fox (1973) reported significant reduction in emergence and growth of red rice, barnyardgrass, broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster], northern jointvetch [*Aeschynomene virginica* (L.) Britton, Sterns & Poggenb.] and hemp sesbania under continuous soil submergence. Hirase and Molin (2002) reported no hemp sesbania emergence in 5 and 10 cm deep water; water depth of even 1 cm reduced the germination by 84%. Submergence of two leaf stage hemp sesbania plants in the same study caused significant growth reduction. Williams et al. (1990) reported strong suppression of barnyardgrass, early watergrass [*Echinochloa oryzoides* (Ard.) Fritsch] and variable flatsedge (*Cyperus difformis* L.) by deep flood, ≤ 20 cm. Sahid and Hossain (1995) also reported complete control of seedling barnyardgrass by 15 cm deep flood. Benvenuti et al. (2004) reported complete inhibition of Chinese sprangletop [*Leptochloa chinensis* (L.) Nees] emergence in floods deeper than 6 cm. Seaman (1983) indentified grass weed suppression as the primary reason for popularization of water-seeding of rice in California in late 1920s and early 1930s. Red rice suppression in water seeding system is cited as the reason for popularity of this system in south Louisiana (Linscombe 1999).

Flooding inhibits weed growth by reducing oxygen availability to the roots (Vartapetian and Jackson 1997). Weeds differ in their ability to tolerate anaerobic conditions (Stoecker et al. 1995) and many weeds like red rice, barnyardgrass, creeping rivergrass [*Echinochloa polystachya* (Kunth) Hitchc.], hemp sesbania, ludwigia [*Ludwigia hyssopifolia* (G. Don) Exell apud A.R. Fernandes], alligatorweed, palmleaf morningglory (*Ipomoea wrightii* A.

Gray); ducksalad [*Heteranthera limosa* (Sw.) Willd.], and purple ammannia are adapted to flooded conditions in the rice paddies (Bottoms 2009; Gealy 1998; Hirase and Molin 2002; Sahid and Hossain 1995; Smith and Fox 1973; Yu et al. 2007).

Plants can mitigate the adverse effects of waterlogging by adjusting dry matter partitioning between shoot and root (Nakayama et al. 2009) and/or by forming aerenchyma in submerged stems and roots (Evans 2004; Shimamura et al. 2007; Solaiman et al. 2007; Thomas et al. 2005). Monocot plants like rice (Kawai et al. 1998) and maize (*Zea mays* L.) (Lenochová et al. 2009) produce cortical aerenchyma in their roots, which provides low resistance pathway for oxygen transport.

In dicot plants secondary aerenchyma, phellem, develop in the phellogen region derived from pericycle cells replaces the function of cortical aerenchyma as an effective stress avoidance system (Shiba and Daimon 2003; Shimamura et al. 2003; Stevens et al. 2002). Secondary aerenchyma forms as a white spongy tissue filled with gas spaces in stems, hypocotyls, tap roots, adventitious roots and root nodules of plants like soybean (*Glycine* spp.), purple loosestrife (*Lathyrus salicaria* L.), sesbania (*Sesbania* spp.) (Saraswati et al. 1992; Shiba and Daimon 2003; Shimamura et al. 2003; Stevens et al. 2002).

Although weed management programs generally involve a complex integration of various cultural, mechanical, biological, chemical, and other methods of weed control. However, owing to its high benefit to cost ratio and tremendous increase in labor productivity, chemical weed control has evolved into a standard weed management approach in crop production systems around the world (Bastiaans et al. 2008; Hill 1982; McWhorter 1984). A number of preemergence (PRE) and postemergence (POST) herbicides are available in rice (Anonymous 2010b) and US rice producers rely primarily on herbicides for weed control; 95% of the rice planted in the United States in 2006 received some type of herbicide application (USDA 2006).

Clomazone [2-[(2-chlorophenyl) methyl]-4,4-dimethyl-3-isoxazolidinone] and quinclorac [3,7-dichloroquinoline -8-carboxylic acid] are the two major PRE herbicides used in rice in the USA (Anonymous 2010a; USDA 2006). Thiobencarb [S-((4-chlorophenyl) methyl)diethylcarbamothioate] and pendimethalin [3,4-Dimethyl-2,6-dinitro-N-pentan-3-yl-aniline] are also used, but to a lesser extent (USDA 2006).

Clomazone belongs to the isoxazolidinone family and provides control of *Echinochloa* spp. (Mitchell and Hatfield 1996; Webster et al. 1999; Zhang et al. 2005). In 2006, 50% of the US rice acreage received clomazone application (USDA 2006). Although, clomazone provides grass control and has very good residual activity in rice (Mitchell and Gage 1999; Mitchell and Hatfield 1996; Webster et al. 1999), it does not control several key broadleaf and sedge species when applied at recommended rates (Brommer et al. 2000; Williams et al. 2004).

Quinclorac controls barnyadgrass (Baltazar and Smith 1994; Street and Muller 1993), hemp sesbania, pitted morningglory (*Ipomoea lacunose* L.), jointvetch (*Aeschynomene* spp.)(Grossmann 1998; Street and Mueller 1993). However, quinclorac has little to no activity on sprangletop (*Leptochloa* spp.)(Jordan 1997; Anonymous 2010a) and the development of quinclorac-resistant barnyardgrass (Lopez-Martinez 1997; Lovelace 2007; Malik et al. 2010) has limited its use in rice.

Pendimethalin and thiobencarb are applied as delayed preemergence (DPRE), which is an application made after rice has imbibed water for germination but before emergence (Anonymous 2010a). Pendimethalin controls grasses and small-seeded broadleaf weeds (Byrd and York 1987) but is not effective against sedges and large seeded broadleaf weeds like spreading dayflower and Texasweed (Anonymous 2010a). Thiobencarb provides good control of barnyardgrass, sprangletop, and annual sedges but has limited activity on broadleaf weeds; the period of residual control is also less than three weeks (Anonymous 2010a).

In general, the available PRE herbicides in rice are very effective against grasses which are the dominant and most troublesome weeds in rice (Holm et al. 1977; Fischer et al. 2004; Valverde et al. 2001). The high degree of residual grass control by these herbicides allows the farmers to delay their POST applications up to 4 to 5 weeks after planting (Bill Williams[1], personal communication). Many broadleaf weeds like Texasweed become very hardy and difficult to control by that time (Godara et al. 2007). Kurtz (2004) also reported reduced activity of POST herbicides on three- to four-leaf Texasweed in soybean crop and emphasized the need for its control at an early stage.

Although, the early season weed control achieved by POST herbicides lays the ground work for a healthy crop; POST weed management is often required to maximize the crop quality and yield (Ampong-Nyarko and DeDatta 1991). Ever since the development of 2,4-D [(2,4-dichlorophenoxy)acetic acid] in 1940s efforts have constantly been made to provide better options of broad-spectrum and effective chemical weed control in rice. Propanil [N-(3,4-Dichlorophenyl) propanamide] first registered in the United States in 1972 (Anonymous 2010b) provides excellent control of grass and broadleaf weeds (Crawford and Jordan 1995; Jordan et al. 1997). However, long-term repeated use of propanil has led to the development of propanil-resistance in barnyardgrass (Baltazar and Smith 1994; Carey et al. 1995; Talbert 2007). Despite the development of propanil resistance in barnyrdgrass, it is still the most widely used POST herbicide in rice (USDA 2006). Other herbicides like quinclorac, triclopyr [[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid], carfentrazone-ethyl [ethyl α,2-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]-4-fluorobenzenepropanoate], and acifluorfen [5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid] also provide postemergence broadleaf weed control in rice (Anonymous 2010a; Jordan 1997; Mitchell and Sims 1998; Rosser et al. 1988). However, the most recent entries in the list of herbicides registered for use in rice are the acetolactate synthase (ALS) (EC 4.1.3.18) inhibiting herbicides.

ALS herbicides used in rice primarily include sulfonylureas and imidazolinones (Anonymous 2010a). Imazethapyr [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid] is an imidazolinone herbicide registered for use in imidazolinone-resistant (IR) rice (Anonymous 2008a). Imazethapyr provides effective control of red rice, barnyardgrass, and broadleaf signalgrass in rice (Klingaman et al. 1992; Masson and Webster 2001; Masson et al. 2001). It has little activity on hemp sesbania, northern jointvetch, and Indian jointvetch (Klingaman et al. 1992; Masson and Webster 2001; Zhang et al. 2001). Mixture of imazethapyr with other herbicides like bispyribac-sodium, carfentrazone, or propanil improves overall weed control, especially hemp sesbania (Zhang et al. 2006).

Bensulfuron-methyl [methyl 2-[[[[[(4,6-dimethoxy-2-pyrimidinyl) amino]carbonyl]amino]sulfonyl]methyl]benzoate] and halosulfuron-methyl [methyl 3-chloro-5-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl] amino]sulfonyl]-1-methyl-1H-pyrazole-4-carboxylate] are the two most popular sulfonylurea herbicides used in rice and were used on about 15% of the U.S. rice acreage in 2006 (USDA 2006). Bensulfuron-methyl provides very good control of broadleaf weeds such as hemp sesbania, eclipta and purple ammania but has limited to no activity on barnyardgrass (Jordan 1995). Halosulfuron is very effective against sedges and has moderate activity on broadleaf weeds (Mudge et al. 2005; Murphy and Lindquist 2002; Zhang et al. 2006).

Penoxsulam [2-(2,2-difluoroethoxy)-6-(trifluoromethyl-N-(5,8-dimethoxy[1,2,4] triazolo[1,5-c]pyrimidin-2-yl))benzenesulfonamide], belongs to the trizolopyrimidine sulfonamide family. It has PRE and POST activity on grass and broadleaf weeds (Johnson et al. 2009). Lassiter et al. (2006) reported that penoxsulam at 20 to 40 g ai/ha applied POST in dry-seeded rice controled alligatorweed, annual sedges (*Cyperus* spp.), annual and perennial *Echinochloa* species, ducksalad [*Heteranthera limosa* (Sw.) Willd.], hemp sesbania, northern jointvetch [*Aeschynomene virginica* (L.) Britton, Sterns & Poggenb.], spreading dayflower, Texas/Mexicanweed, smartweed (*Polygonum* spp.), and several other broadleaf weeds. Penoxsulam provides 2 to 4 weeks of residual weed control in dry-seeded rice. Strahan (2004) reported 83 and 85% Texasweed control 70 days after treatment (DAT) with penoxsulam at 40 and 51 g/ha, respectively. Williams et al. (2004), however, reported only 40% hemp sesbania control two weeks after flooding with a PRE application of penoxsulam at 30 g/ha plus clomazone at 560 g ai/ha in drill-seeded rice. The control of barnyardgrass, Amazon sprangletop [*Leptochloa panicoides* (J. Presl) Hitchc.], and rice flatsedge (*Cyperus iria* L.) in the same treatment was 90, 70, and 86%, respectively. Penoxsulam had greater broadleaf activity when applied POST.

Bispyribac-sodium [Sodium 2,6-bis[(4,6-dimethoxypyrimidin-2-yl)oxy]benzoate], belongs to the pyrimidinyl thiobenzoates family and provides POST control of certain grass and broadleaf weeds in rice (Anonymous 2008b). Bispyribac-sodium provides broad-spectrum weed control in rice but has no residual activity (Esqueda and Rogales 2004). Bispyribac-sodium at 20 and 22 g ai/ha to four- to six-leaf rice controlled of barnyardgrass, hemp sesbania, and northern jointvetch (Schmidt et al. 1999). Williams (1999) reported 98 to 100% barnyardgrass and hemp sesbania control from MPOST and LPOST applications of bispyribac-sodium at 20 or 23 g/ha.

Mixing of two or more herbicides is extensively practiced in modern crop production systems to reduce the cost of application and broaden the spectrum of weed control. Newly labeled herbicides are, therefore, evaluated in mixture with other herbicides recommended for the crop. These field level trials are aimed at integrating new herbicides into already established weed management programs. Mixing of herbicides is generally based on the assumption that herbicides in a mixture behave and act independently (Damalas 2004). However, the interaction between component herbicides in a mixture can alter their chemical properties and can increase or decrease their activity compared to the component herbicides applied individually (Damalas 2004). An increase or decrease in weed control due to herbicide mixture implies synergism or antagonism, respectively; the effect is called additive if the mixture results in a weed control level equal to the sum of that obtained with each herbicide applied alone (Colby 1967; Green 1989; Hatzios and Penner 1985). An optimum herbicide combination or mixture would be one that provides either additive or preferably synergistic effect on target weeds without any toxicity to the crop.

The type and the magnitude of interaction between component herbicides in a mixture primarily depends on the herbicide properties including chemical family, absorption, translocation, mechanism of action, pathway of metabolism as well as on the weed or crop species involved (Damalas 2004). In an extensive summary of studies on herbicide-herbicide interactions Zhang et al. (1995) observed that regardless of the plant species or herbicides involved, antagonism occurs three times more often than synergism. Damalas (2004) concluded that in general, antagonism occurs more frequently in grass weeds than broadleaf weeds and also in mixtures where the component herbicides belong to different chemical families. Conversely synergism occurs more frequently in broadleaf weed species and in mixtures where the component herbicides belong to the same chemical family. Based on the concentration addition (CA) model Cedergreen et al. (2007) did not find any antagonistic interaction between herbicides with the same molecular site of action. However, herbicides with different site of action showed significant antagonism in 70% of the mixtures.

ALS inhibiting herbicides generally show antagonism with the herbicides having other modes of action; the interaction with other ALS inhibiting herbicides is mostly additive or synergistic (Cedergreen et al. 2007; Green 1989; Nelson et al. 1998; Schuster et al. 2008; Zhang et al. 2005). Cedergreen et al. (2007) reported additive interaction between metsulfuron-methyl [2-[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]-oxomethyl]sulfamoyl]benzoic acid methyl ester] and triasulfuron [1-[2-(2-chloroethoxy)phenyl]sulfonyl-3-(4-methoxy-6-methyl-1,3,5-triazin-2-yl)urea]. Simpson and Stoller (1995 and 1996) reported synergistic interaction between thifensulfuron [3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid] at 4.4 g ai/ha and imazethapyr [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid] at 70 g ai/ha on sulfonylurea tolerant soybean (STS). Simpson and Stoller (1995) also reported significantly higher control of smooth pigweed (*Amaranthus hybridus* L.), common lambsquarters (*Chenopodium album* L.), velvetleaf (*Abutilon theophrasti* Medik.), common cocklebur (*Xanthium strumarium* L.), tall morningglory [*Ipomoea purpurea* (L.) Roth], and ivyleaf morningglory (*Ipomoea hederacia* Jacq.) with thifensulfuron at 4.4 g/ha plus imazethapyr at 70 g/ha as compared to these herbicides applied alone. Reducing the rate of one or both herbicides did not decrease smooth pigweed and common cocklebur control. Nelson et al. (1998) also reported greater common lambsquarter control with thifensulfuron at 2.2 g/ha plus imazethapyr at 70 g/ha compared with these herbicides applied alone. Damalas et al. (2008) reported higher efficacy of bispyribac-sodium plus azimsulfuron [N-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]-1-methyl-4-(2-methyl-2H-tetrazol-5-yl)-1H-pyrazole-5-sulfonamide] on early watergrass [*Echinochloa oryzoides* (Ard.) Fritsch] and late watergrass [*Echinochloa phyllopogon* (Stapf) Koso-Pol.] compared with bispyribac-sodium applied alone. The increased weed control was dependent on bispyribac-sodium rate and weed stage at the time of herbicide application. Godara et al. (2007) reported higher broadleaf weed control in rice with mixtures of penoxsulam or bispyribac-sodium with bensulfuron-methyl compared with these herbicides applied alone; suggesting interaction between the component herbicides in the mixtures.

V-10142, imazosulfuron, [2-chloro-N-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]imidazo[1,2-a]pyridine-3-sulfonamide], an ALS inhibitor, is being developed by Valent Co. USA[2] for weed control in drill- and water-seeded rice. It primarily controls broadleaf weeds and sedges but can suppresses annual grass weeds (Baron 2006). Boydston and Felix (2008) reported 91 to 98% yellow nutsedge (*Cyperus esculentus* L.) control with V-10142. Henry and Slaeek (2008) reported 90 to 100% yellow nutsedge and up to 90% purple nutsedge (*Cyperus rotundus* L.) control in bermudagrass [*Cynodon dactylon* (L.) Pers.] with two POST applications of V-10142 at 560 g ai/ha. Imazosulfuron may prove to be an effective PRE herbicide for broadleaf weed and sedge control in drill-seeded rice. The herbicide if compatible in mixture with bispyribac-sodium or penoxsulam also has potential to provide broad-spectrum POST weed control in drill-seeded rice.

The research for this dissertation addressed the following objectives:

1. To study Texasweed interference in drill-seeded rice.
2. To study the effect of shade on Texasweed emergence, growth and reproduction.
3. To study the effect of flood depth on Texasweed growth and reproduction.
4. To study bensulfuron-methyl interaction with penoxsulam and bispyribac-sodium in mixture for Texasweed control in drill-seeded rice.
5. To evaluate V-10142 for Texasweed control in drill-seeded rice.

End Notes

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Chapter 2

Texasweed (*Caperonia palustris*) Interference in Drill-Seeded Rice

Introduction

Texasweed [*Caperonia palustris* (L.) St. Hil.], also known as sacatrapo (USDA 2007), is an annual broadleaf plant belonging to the Euphorbiaceae family (USDA 2007). It has smooth cotyledons and coarsely pubescent stems and petioles. Leaves are 3 to 15 cm long, alternate, broadly lanceolate, and serrated on the margins (Bryson and DeFelice 2009). Seed are dark brown, 2.5 mm in diameter, and minutely pitted. The plant can attain a height of up to three meters. Texasweed is often mistaken for Mexicanweed [*Caperonia castenifolia* (L.) St. Hil.], which is a perennial plant with a glabrous stem (Godfrey and Wooten 1981.

The invasive and noxious weeds list of the NRCS, USDA describes Texasweed as native to the United States (USDA 2007). However, it has also been described as an invasive (Anonymous 2007), non-native naturalized (Gann et al. 2007) species in the southern United States and native to warmer parts of South America south of Paraguay (Godfrey and Wooten 1981). Texasweed has existed in the Unites States as a wetland plant (Godfrey and Wooten 1981) but has not been a major problem in the crop areas. Lately, it has become increasingly more common in rice, cotton, and soybean fields in the states of Texas, Louisiana, Mississippi, and Arkansas (Koger et al. 2004; Poston et al. 2007).

Gianessi et al. (2002) reported Texasweed as the most troublesome broadleaf weed in Texas and Louisiana rice production systems. Overall it was ranked 3rd and 5th most troublesome weed in the rice production systems of the two states, respectively. Bennett (2003) also reported Texasweed as an emerging problem in Arkansas rice fields. Texasweed grows taller than the rice crop and forms a woody stem (Koger et al. 2004). It is reported to reduce harvest efficiency of combine harvesters particularly in rice (Bennett

2003). Red rice which grows taller than rice and accumulates a lot of vegetative biomass also reduces rice harvest efficiency (Dunand 1988; Smith 1968). Besides reducing the harvest efficiency, the dark brown or grey colored Texasweed seeds are a great concern to the rice growers. The seeds can be an important source of contamination in rice and result in a lower price due to dockage (Bill Williams[1], Personal communication).

Little to no literature on Texasweed interference with rice or other crops exists. However, other broadleaf weeds can cause yield losses in rice (Smith 1968, 1984; Caton et al. 1997, Zhang et al. 2004). Smith (1968) reported that season long interference of hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh] or northern jointvetch [*Aeschynomene virginica* (L.) Britton, Sterns & Poggenb.] at five plants/m^2 reduced rice yield by 19 and 17%, respectively. Interference for four weeks, however, caused only 2% yield loss. Shading caused by these weeds at the time of rice grain filling was identified as the primary reason for the observed yield losses.

Smith (1984) reported 18% yield loss in rice due to season long spreading dayflower (*Commelina diffusa* Burm. f.) interference at 22 plants/m^2. Caton et al. (1997) reported 39% rice yield reduction due to purple ammannia (*Ammannia coccinea* Rottb.) at 100 plants per square meter in a glasshouse study. Zhang et al. (2004) reported 45% rice yield loss due to alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.] interference.

Rice is generally succeptible to broadleaf interference. However, in order to develop integrated management strategies, specific nature of crop-weed interaction warrents investigation. Thus, considering the reports of Texasweed infestation in rice, research was conducted to evaluate Texasweed interference in drill-seeded rice.

Materials and Methods

General. Field studies were conducted in 2007, 2008, and 2009 to evaluate Texasweed interference with rice. In 2007 through 2009, the effect of Texasweed density on rice yield was evaluated. In 2008 and 2009, the area of Texasweed influence and the critical period of Texasweed interference with rice were determined. Experiments were conducted at the Louisiana State University AgCenter’s Northeast Research Station near St. Joseph, Louisiana on Sharkey clay soil (very fine, montmorillonitic, nonacid, Vertic Haplaquept) with pH 6.1 and 2.1% organic matter.

Field preparation during each year consisted of a fall disking followed by a spring disking and two passes in opposite directions with a two-way bed conditioner equipped with rolling baskets and S-tine harrows set to operate 15 cm deep. ‘Cocodrie’ rice was drill-seeded at 100 kg/ha on May 22, April 29, and June 02 in 2007, 2008, and 2009, respectively. Plots consisted of eight-19 cm spaced rows 4.5 m long.

The study area was surface irrigated immediately after application of preemergence (PRE) herbicides and as needed. A 10 cm permanent flood was established 5 to 6 weeks after planting when rice reached the four to five leaf stage and was maintained until 2 weeks prior to harvest. Nitrogen in the form of prilled urea (46-0-0) was applied at 126 kg/ha just before permanent flood. At panicle initiation an additional 42 kg/ha of nitrogen was applied.

Grasses were managed by a preemergence application of clomazone[2] at 560 g ai/ha and postemergence application of cyhalofop-ethyl[3] at 313 g ai/ha or fenoxaprop-ethyl[4] at 122 g ai/ha. Clomazone, cyhalofop-butyl and fenoxaprop-ethyl have limited to no activity on Texasweed and other broadleaf weeds (Anonymous 2010). Hemp sesbania, the only other major broadleaf weed in the experimental area, was removed by hand weeding as needed. Herbicides were applied using a CO_2 pressurized backpack sprayer calibrated to deliver 140 L/ha at 276 kPa.

Texasweed Density Study. Treatments consisted of Texasweed densities ranging from 0 to 50 plants/m^2 (Figure 2.1). Texasweed densities were established either by hand-weeding in experimental plots already having natural variation in Texasweed density or by by planting Texasweed seeds[5]. Two experiments were conducted with natural population and two with planted population. Texasweed plants emerged before or along with rice in the experiments involving natural Texasweed population; however, in experiments involving Texasweed seed planting there was a lag of about 7 to 10 days between rice and Texasweed emergence. In all the experiments Texasweed was allowed to interfere with rice seasonlong.


Figure 2.1 Texasweed interference study (planted population 2009).

Texasweed density was recorded by counting the number of plants in one meter square area in the center of each plot 2-6 days prior to permanent flood establishment. Rice height, rough rice yield, yield components, and rice sample moisture data were recorded at the time of rice harvest. Rice height was obtained by measuring five rice plants per plot from the ground to the tip of the extended panicle. Other parameters were obtained from whole plant samples hand harvested from two meter row length from the two center rows in the middle of each plot. Filled grains from 10 panicles randomly selected from the harvested samples were used to calculate grains per panicle and 1000-grain weight. Rough rice yield and rice sample moisture data in 2007 and 2008 were obtained by harvesting the whole plot using a small plot combine. However, in 2009 small plot combine could not be used because of inclement weather at the time of harvest and rice yield data were obtained by threshing the whole plant samples hand harvested from one meter square area in the middle of each plot. The rice harvest sample moisture data at harvest were not collected in 2009 because combine harvester was not used for harvesting.

The rough rice yield data were converted to percent yield loss as compared with the weed-free. The average of the observations for weed-free was used to convert the data to percent yield loss. The percent yield loss and sample moisture data were subjected to regression analysis to model these response variables as a function of Texasweed density. A graphical examination of the data showed non-linear relationship of both percent yield loss and sample moisture with Texasweed density. Therefore, NLMIXED procedure of SAS (SAS 2003) was used to fit nonlinear models. Null-model likelihood ratio tests for nested models and Akaike's information criteria (AIC) values for unrelated models were used to compare different models and the criteria of better fit and parsimony was used to select a final model. For both percent yield loss and rice sample moisture data, the models with year as a random effect had a very poor fit and provided non-homogeneous variance for the residuals. A visual examination of scatter plots of response variables against Texasweed density also showed possible year effect. Therefore, year was used as a fixed effect.

A path coefficient analysis was also carried out to study the direct and indirect effect of Texasweed density on yield components and rough rice yield. A path coefficient diagram is a priori model of cause-and-effect relationship between confounded variables (Donald and Khan 1996). Unlike multiple regression or correlation analysis, path coefficient analysis does not assume independence among predictor variables. In fact, changes in one predictor variable are assumed to cause changes in other predictor variables for a given data set, i.e. predictor variables are “confounded” and change in an interdependent compensatory way. Path analysis cannot be used to demonstrate the causality, but it can be used to study the implications of assuming a particular model of causation between confounded variables (Donald and Khan 1996). In the path analysis used for this study, it was hypothesized that Texasweed density reduces rough rice yield through its effect on yield components. Thus, the effect of Texasweed density on rough rice yield was not assumed to be direct but mediated through its effect on culms per unit area, grains per panicle, and 1000-grain weight. The three yield components were assumed to have a compensatory relationship with each other, where each changes in response to change in others. Path analysis was carried out using the TCALLIS procedure of SAS (SAS 2008).

Area of Influence Study. Five Texasweed seeds[5] were planted in the center of each rice plot just after rice planting. The Texasweed plants were thinned to one plant per plot three days after emergence. The experimental plots (Figure 2.2a) were kept weeds-free other than the central Texasweed plant in each plot using PRE and postemergence POST herbicides and hand weeding. The central Texasweed plants in the experimental plots were shielded from herbicides by covering them with a plastic pot of 15 cm diameter at the time of herbicide application. The area just near the Texasweed plant was kept weed free by hand weeding.

Rice was harvested from four 20 cm wide concentric circular bands around the central Texasweed plant in each experimental plot (Figure 2.1b). Rice from 8 and 10 plots was harvested in this manner in 2008 and 2009, respectively. The experimental design thus obtained was a repeated measure in distance. The individual plots were considered as subjects and distance from the central Texasweed plant was the repeated measure. The four repeated measures, thus, were the increasing distances of 20, 40, 60, and 80 cm from the single Texasweed plant in the center of each plot. The 20 cm band width was chosen because rice was drilled in rows spaced 19 cm apart; thus, each repeated measure included one rice row on each side of the Texasweed plant.

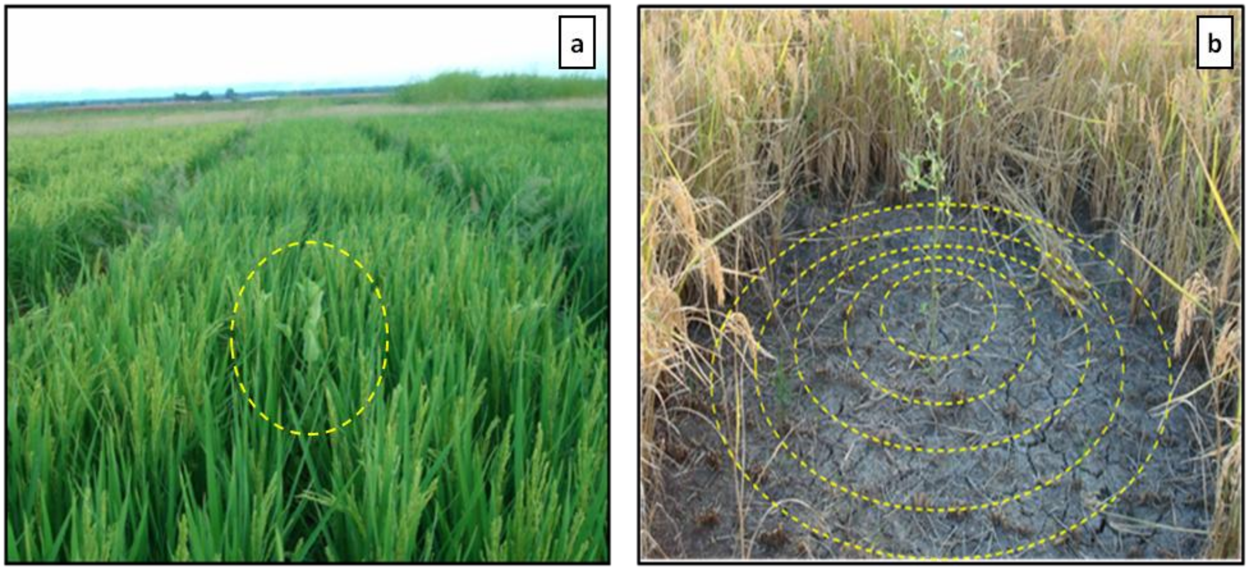

Figure 2.2 Area of influence study (a) central Texasweed plant in a plot;(b) harvest scheme, 20 cm concentric bands.

Rice height, yield, harvest index, culms/m^2, grains per panicle, and 1000-grain weight were recorded from the harvested samples. Rice height was obtained by measuring five rice plants per plot from the ground to the tip of the extended panicle. Culms/m^2 were calculated by dividing total number of culms in the harvest sample by the area harvested. Total number of grains and filled grains in each harvest sample were counted using a seed counter[6] and percentage of filled grains was calculated for each sample. Filled grains were used to calculate rough rice yield, grains per panicle and 1000-grain weight. Rough rice yield was calculated by dividing the total weight of filled grains by the respective area harvested for each sample. Harvest index was calculated by dividing the rough rice yield by the dry weight of the whole harvested sample. Grains per panicle were calculated by dividing the total number of filled grains by the number of culms in the harvested sample. Thousand-grain weight was obtained by dividing the weight of filled grains by the number of filled grains for each sample and multiplying by 1000.

Data were analyzed for testing the effect of distance from the central Texasweed plant on rice growth, yield and yield components using MIXED procedure of SAS (SAS 2003). Year and plot within a year were considered random effects. Distance from the central Texasweed plant was considered a repeated measure with plot within year as subject. Tukey's test was used for mean separation. Letter groupings were generated using the PDMIX800 macro in SAS (Saxton 1998). Linear and quadratic contrasts were also constructed to study the response as a function of the distance from central Texasweed plant.

Critical Period Study. The critical period of weed control (CPWC) is defined as the period after crop establishment during which the yield losses due to unmanaged weeds exceeds the acceptable yield loss (AYL) (Knezevic et al. 2002). AYL is the yield loss level at which the cost of the weed management practice is equal to the benefit from employing it. AYL is generally assumed to be 2 to 10% (Cousens 1988; Knezevic et al. 2002); however, it can vary depending on the benefit-cost ratio of the weed management practice (Knezevic et al. 2002). Critical periods are composed of two components, viz., the critical weed-free period (CWFP) required to obtain at least (100-AYL)% of the yield obtained under season long weed-free conditions and the critical period of weed removal (CPWR) which is the time after which unmanaged weeds cause a yield reduction greater than AYL (Knezevic et al. 2002).

The experiments were laid out in randomized complete block (RCB) block design with three replications and were conducted using a natural population of Texasweed. The average density in 2008 and 2009 was approximately 40 and 15 plants/m^2. Treatments included weed competition periods of 0, 1, 2, 3, 4, 6, 8, and 12 weeks after emergence (WAE) and weed-free periods of 0, 1, 2, 3, 4, 6, 8, and 12 WAE. Rice reached maturity at 16 WAE, therefore, season long weed-free plots were considered weed-free up to 16 WAE. Similarly, season long weedy plots were considered weedy up to 16 WAE. Various treatments were imposed using selective herbicides and/or hand-weeding. Weed interference period treatments were imposed using bispyribac-sodium[7] at 29 g ai/ha plus V-10142[8] at 224 g ai/ha. Bispyribac-sodium and V-10142 combination was used as it provided excellent season long Texasweed control in our earlier experiments. Weed-free period treatments were imposed using carfentrazone-ethyl[9] at 18 g ai/ha and hand weeding. Cafentrazone-ethyl controls Texasweed shorter than 10 cm (Anonymous 1998) and provided 100% control of cotyledon stage Texasweed in the experimental plots. Cafentrazone-ethyl has limited to no residual activity at the rates used (Anonymous 1998); therefore, did not affect Texasweed emergence after intended weed-free period.

Rough rice yield data in 2008 were obtained by harvesting the whole plots using a small plot combine. In 2009 small plot combine could not be used because of inclement weather at the time of harvest and yield data were obtained by threshing the whole plant samples hand harvested from 1 m^2 area in the middle of each plot. Rough rice yiled was adjusted to 12% moisture. Yield data were converted to relative yield, % of weed-free.

The data were subjected to regression analysis to model the relative yield as a function of weed-free or weed-competition period. The average of the observations for weed-free control was used to convert the data to percent of control. Several non-linear growth curves as suggested in literature (Cousens 1988; Hall et al. 1992; Knezevic et al. 2002) were fitted to weed-competition period and weed-free period data. NLMIXED procedure of SAS (SAS 2003) as described by Knezevic et al. (2002) was used to fit various nonlinear models. A visual examination of the scatter plots of the response variables against weed-free period or weed-competition period showed possible year effect. Thus, models with year as a random or fixed effect were evaluated. Null-model likelihood ratio tests for nested models and Akaike's information criteria (AIC) values for unrelated models were used to compare different models and the criteria of better fit and parsimony was used to select a final model. The AYL level used to predict the critical period of weed interference was set at 5%.

Results and Discussion

Texas Density Study. Texasweed density did not affect rice height (data not presented). The response of rice yield to Texasweed density was significant. Percent yield loss data were best described using the rectangular hyperbolic model (Equation 2.1) (Cousins 1985).

$$Y = aX/(1+aX/b) \qquad \text{[Equation 2.1]}$$

Where, Y is percent yield loss, X is Texasweed density, a is the percent yield lost to each additional weed when X approaches zero, and b is an asymptote corresponding to the maximum relative yield loss when X tends to infinity.

There was no difference between experiments conducted in 2008(P), 2008(N) and 2009(P). Yield reduction as a function of Texasweed density for these experiments could be modeled with the same set of parameters. The experiment conducted in 2007 (N), however, deviated significantly in terms of parameter ‘b’. The maximum possible yield reduction in 2007 was 44% which was lower than 81% estimated for other experiments (Figure 2.3). The difference in ‘b’ parameter between the two years was due to relatively lower rice yield in season-long Texasweed free plots in 2007. Barnyardgrass which was the dominant grass in the experimental area could not be controlled effectively in 2007 and reduced rice yield in Texasweed free plots also.

There was no difference between the experiments for parameter ‘a’ and it was estimated to be 5.1% (Figure 2.3) indicating that season long interference due to one Texasweed plant/m^2 can reduce drill-seeded rice yields by 5.1%. Texasweed infestation at 50 plants/m^2 was estimated to cause 61% yield loss. Even 10 plants/m^2 caused 24 to 31% yield reduction.

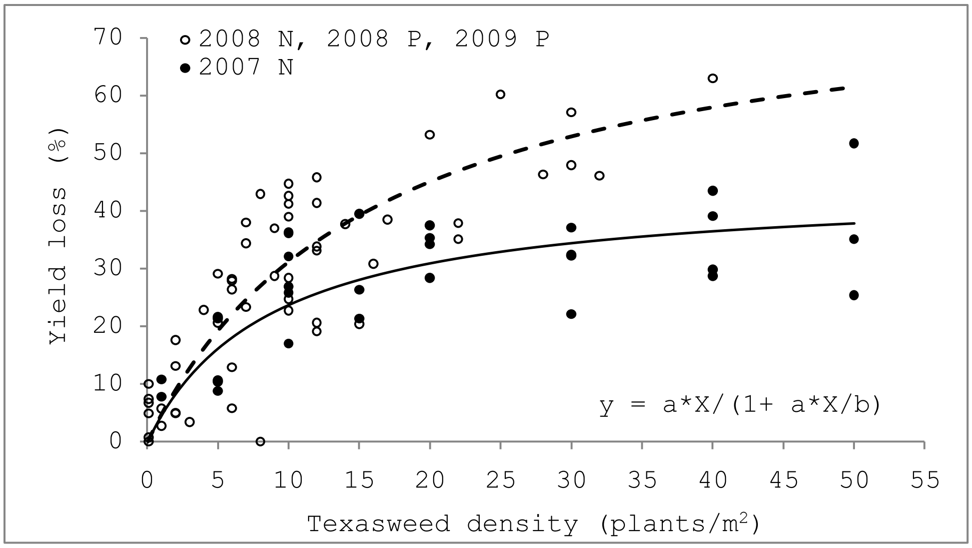

Figure 2.3 Effect of Texasweed density on rough rice yield. Equation 2.1, where y and x are the yield loss and Texasweed density, respectively. N and P in the legend stand for natural and planted populations, respectively. Parameter and standard errors (in parentheses) were a = 5.07(0.64), and b = 81.20(10.62) for 2008 N, 2008 P and 2009 P; a = 5.07(0.64), and b = 44.40(3.91) for 2007 N.

The results of the path coefficient analysis carried out to study the cause-and-effect relationship between rough rice yield and yield components are presented in Figure 2.4 and Table 2.1. Double-headed arrows in the path diagram illustrate the assumption that change in two variables compensates for one another (Figure 2.4). Single-headed arrows illustrate that one variable is assumed to affect another without being influenced by it. In the path analysis, Texasweed was assumed to reduce rough rice yield by affecting yield components. The results (Figure 2.4) shows that an increase in Texasweed density caused a reduction in the number of culms (p=-0.47) and thus reduced rice yield (Table 2.1). Texasweed density did not affect 1000-grain weight of rice, which is indicated by the non-significant path coefficient (Figure 2.4). Thousand-grain weight also had no direct effect on rough rice yield (Figure 2.4 and Table 2.1). Texasweed interference also reduced grains per panicle (p=-30.0), that ultimately reduced yield (Table 2.1). Although both the number of culms per unit area and grains per panicle were adversely affected by the increasing Texasweed density, the significant negative correlation (r=-0.44) between culms per square meter and grains per panicle indicated yield component compensation (Figure 2.4). The reduction in number of culms per unit area was compensated to some degree by an increase in number of grains per panicle. However, this effect was not strong enough to reverse the detrimental effect of reduced culms per unit area on rough rice yield. The results indicate that Texasweed reduces rough rice yield by affecting both culms per unit area and grains per panicle. This is in contrast to the findings of Smith (1968) on hemp sesbania and northern jointvetch and Smith (1984) and spreading dayflower interference in rice where reduction in rice yield was attributed to decreased grain filling due to shading.

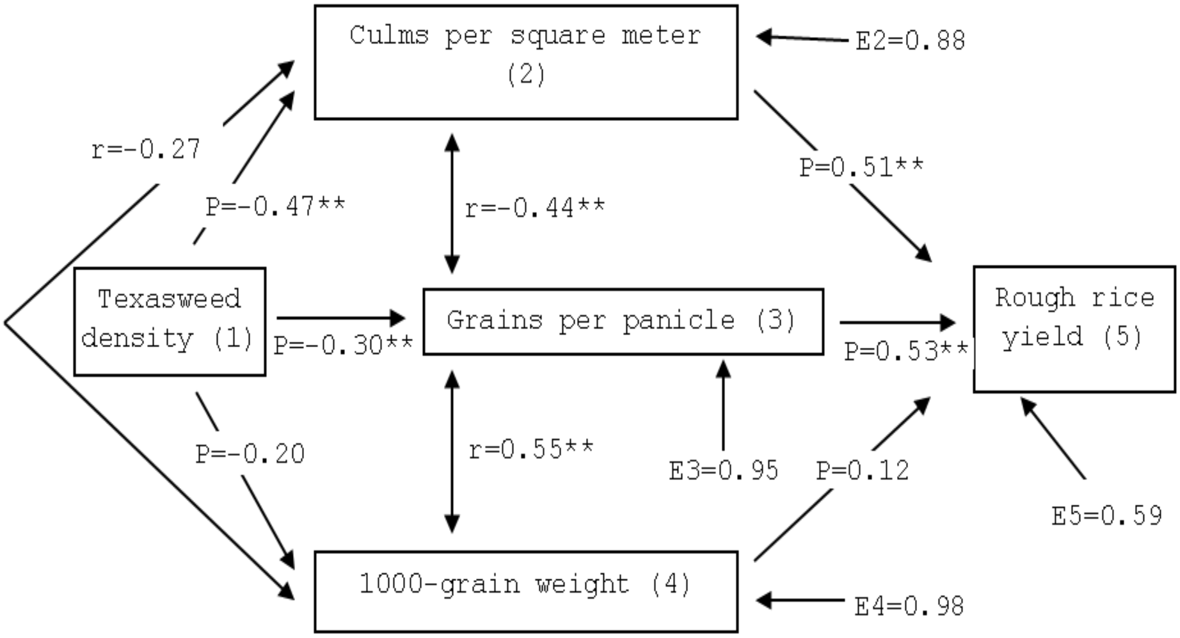

Figure 2.4 Diagrammatic representation of direct and indirect effect of yield components on rough rice yield in interference experiments conducted using planted densities. Single-arrowed lines represent direct influences measured by path coefficients (p), double-arrowed lines indicate correlation coefficients (r), and ‘e’ represents residual error. Positive or negative values of the coefficient ‘p’ implies an increase or decrease in affected variable, respectively, due to an increase in affecting variable. Coefficients marked with asterisks are significantly different from zero: *, P≤0.05; **, P≤0.01.

Table 2.1 Path of association between the response variable rough rice yield and the direct and indirect predictor variables culms per square meter, grains per panicle, 1000-grain weight, and Texasweed density; combined analysis of 2008(P) and 2009(P) data.

Path of association	Calculations[a]	Value
Culms per square meter → Rough rice yield		
Direct effect	p25	0.51
Indirect effect via grains per panicle	r23*p35	-0.23
Indirect effect via 1000-grain weight	r24*p45	-0.03
Total correlation	r25	0.25
Grains per panicle → Rough rice yield		
Direct effect	p35	0.53
Indirect effect via culms per square meter	r23*p25	-0.22
Indirect effect via 1000-grain weight	r34*p45	0.07
Total correlation	r35	0.38
1000-grain weight → Rough rice yield		
Direct effect	p45	0.12
Indirect effect via culms per square meter	r24*p25	-0.14
Indirect effect via grains per panicle	r34*p35	0.29
Total correlation	r45	0.27
Texasweed density → Rough rice yield		
Indirect effect via culms per square meter	p12*p25	-0.24
Indirect effect via grains per panicle	p13*p35	-0.16
Indirect effect via 1000-grain weight	p14*p45	-0.02

[a] p=Path coefficient and r=correlation coefficient obtained from figure 2.4.

Texasweed density also had a significant effect on the moisture content of the rice grain sample at harvest. The traditional VonBertalanffy model in Equation 2.2 was found to fit each year’s data best.

$$Y = Y_{max}(1-\exp(-b(X-X0))) \qquad \text{[Equation 2.2]}$$

Where, Y is moisture percent, X is Texasweed density, Y_{max} is the moisture percent as X approaches infinity, X0 is the density point where Y is zero, and b is a rate coefficient.

Increasing Texasweed density increased moisture content of rice harvest sample (Figure 2.5). There was no difference between planted and natural Texasweed populations. The maximum sample moisture in 2007 was 20% which was lower than 29% estimated for 2008. Also the inflection point occurred at 54 plants/m^2 for year 2007 and at 27 plants/m^2 for year 2008 (Figure 2.5). The higher moisture content of rice harvest samples was probably due to a contamination with Texasweed capsules which were still green at the time of harvest (Figure 2.6a, 2.6b). The difference between the two years could be due to difference in combine settings, which might have affected the amount of Texasweed capsules in the harvested sample. Despite the difference in the parameterization of the model for years 2007 and 2008 as discussed above, the results shows that increasing Texasweed densities increased the moisture content of rice harvest samples. The high moisture content of harvested rice can result in dockage if delivered to elevator or increasd cost if dried on farm. The harvest sample from plots having high Texasweed density also had higher contamination of Texasweed seeds (Figure 2.6c); however, no effort was made to quantify.

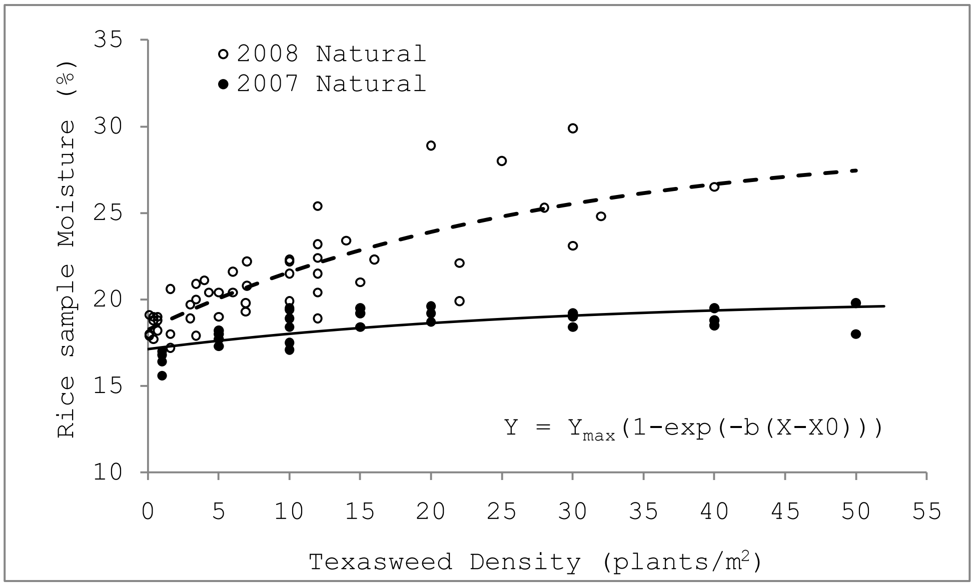

Figure 2.5 Effect of Texasweed densities on moisture content of rice harvest sample. Equation 2.2, where Y and X are the moisture percent and Texasweed density, respectively. Parameter and standard errors (in parentheses) were Y_{max}=20.07(2.84), b=0.036(0.017), and X0=53.33(16.95) for year 2007; Y_{max}=29.29(3.32), b=0.036(0.017), and X0=27.12(8.72) for year 2008.

Figure 2.6 (a) a rice plot at the time of harvest; (b) Texasweed plant still green at the time of rice harvest; (c) rice sample from one of the weedy plots.

Area of Influence Study. Rice height and 1000-grain weight were not affected by the distance from the central Texasweed plant (data not presented). The linear and quadratic contrasts for these responses were also not significant. The effect of distance from Texasweed plants was significant on rough rice yield, culms per square meter, harvest index, grains per panicle, and percent filled grains (Table 2.2). Rice yield within 20 cm of the Texasweed plant was lower than that observed beyond 20 cm. The differences between 40, 60, and 80 cm distances were not significant. The significant quadratic trend (Table 2.2) also showed decreasing influence of Texasweed interference with increasing distance from the Texasweed plant. Rice within 20 cm of the Texasweed plant produced fewer culms per meter square than the rice beyond 20 cm. The significant linear and quadratic contrasts also indicated an increase in culms per square meter with increasing distance from the Texasweed plant in each plot. Harvest index, grains per panicle and percent filled grains also increased as a function of distance from the central Texasweed as indicated by the significant linear contrasts. ANOVA results, however, showed no difference for these characters between 40, 60 and 80 cm.

Table 2.2 Effect of the distance from central Texasweed plant on rough rice yield and yield components, averaged over 2008 and 2009.[a]

Distance (cm)	Grain Yield (kg/ha)		Culms/m^2		Harvest Index (%)		Seeds/ panicle		Filled grains (%)	
20	2608	b	263	b	35.7	b	72	b	45.4	b
40	4432	a	316	a	41.8	ab	80	ab	54.4	a
60	4719	a	305	a	43.6	a	85	a	54.0	a
80	5010	a	321	a	43.8	a	85	a	53.5	ab
Contrasts	----------------------- p-value -----------------------									
Linear	0.0002		0.0007		0.0095		0.0158		0.0100	
Quadratic	0.0423		0.0504		0.1225		0.1763		0.0117	

b Means within each column followed by a common letter are not significantly different at P = 0.05 using Tukey's test.

Critical Period Study. A four parameter logistic model (Equation 2.3) with year as a fixed effect (separate sets of parameters for each year) provided best fit for both weed-free and weed-competition period data.

$$Y = Y_{max} + [(Y_{max}-Y_0)/(1+\exp(-(X-X_0)/b))] \qquad \text{[Equation 2.3]}$$

Where, Y is the rice yield relative to season-long weed-free treatment, and X is weeks after rice emergence (WAE), Y_{max} is the upper asymptote, Y_0 is the lower asymptote, X_0 is the time at which inflection occurs, and b is the slope at the inflection point.

The difference between the two years in terms of the maximum yield loss resulted in a better fit of the model with year as fixed effect and yielded a different set of parameters for each year. Season long weed interference caused 65 and 24% yield loss in 2008 and 2009, respectively (Figure 2.7, 2.8). Rice planting in 2009 was delayed due to inclement weather conditions and a large number of Texasweed plants emerged in the experimental area before rice planting. The emerged weeds were controlled using glyphosate[10] and rice was planted with minimal soil disturbance; following which Texasweed population in the experimental area remained relatively low, 15 plants/m^2, in 2009 compared to 2008, 40 plant/m^2. This difference in the average Texasweed density in the experimental area seems to be responsible for the different yield loss in the season long weedy plots of the two years.

Although the statistical analysis provided a different model for each year, the results in terms of critical period of Texasweed interference were similar. Critical weed-free period (CWFP) was estimated to be between 5 and 6 WAE in both the years (Figure 2.7, 2.8). Weed-free conditions maintained until 6 WAE provided yield similar to season long weed-free treatment. This may be attributed to the fact that Texasweed did not emerge after permanent flood establishment which was around 6 WAE. Weed-free periods of 2 and 4 WAE also provided higher yields than the season long weedy plots. The critical period of weed removal (CPWR) was estimated to be 0 and 2 WAE in 2008 and 2009, respectively (Figure 2.7, 2.8). The difference in CPWR between the two years may be due to the difference in Texasweed density as discussed earlier. Martin et al. (2001) also emphasized the importance of weed density in determining critical period of interference.

Texasweed interference for 4 WAE accounted for more than 50% of the yield loss caused by season long interference (Figure 2.7, 2.8). This is in contrast to the finding of Smith (1968, 1984) for other weeds like hemp sesbania, northern jointvetch and spreading dayflower. Smith (1968) reported that at 5 plants per square meter density, hemp sesbania and northern jointvetch interference for four weeks caused only 2% yield loss in drill-seeded rice. Whereas, the yield loss due to season long interference of the two weeds was 19% and 17%, respectively. He also concluded that these weeds reduced rice yield primarily due to shading effect at the time of rice grain filling and were not competitive if removed before they were tall enough to shade the rice plants. Smith (1984) also reported similar finding with spreading dayflower; season long interference at 22 plants/m^2 caused 18% rice

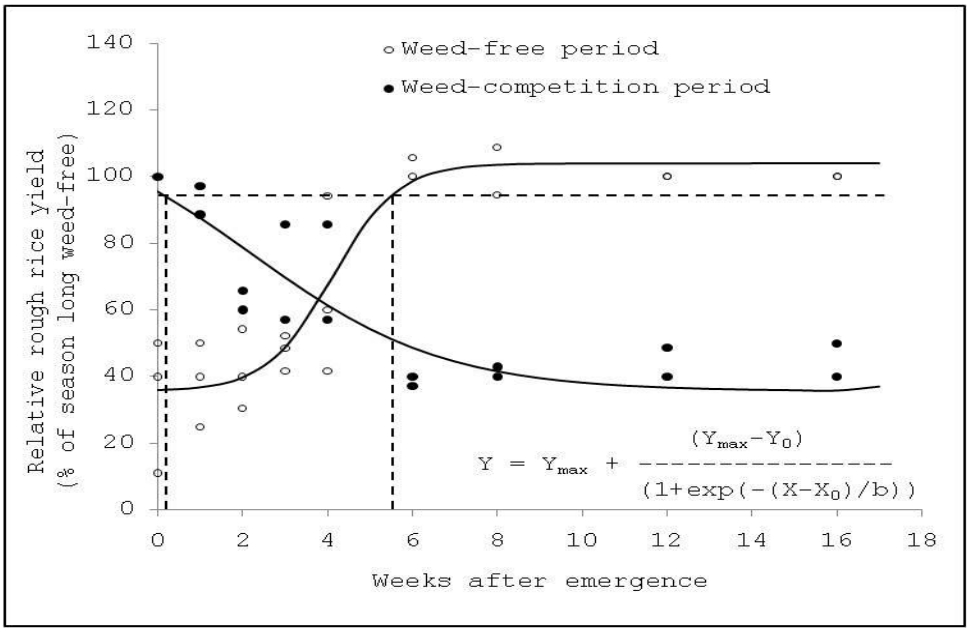

Figure 2.7 The effect of Texasweed interference and weed-free periods on relative rice yield in 2008. Equation 2.3, where Y and X are the relative rice yield and weeks after rice emergence (WAE), respectively. Parameter estimates and standard errors were Y_{max}=118.15(14.36), Y0=35.56(4.70), b=2.27(0.80), and X0=2.22(1.14) for weed interference period; Y_{max}=103.96(2.92), Y0=35.53(5.50), b=-0.7693(0.32), and X0=4.12(0.31) for weed-free period.

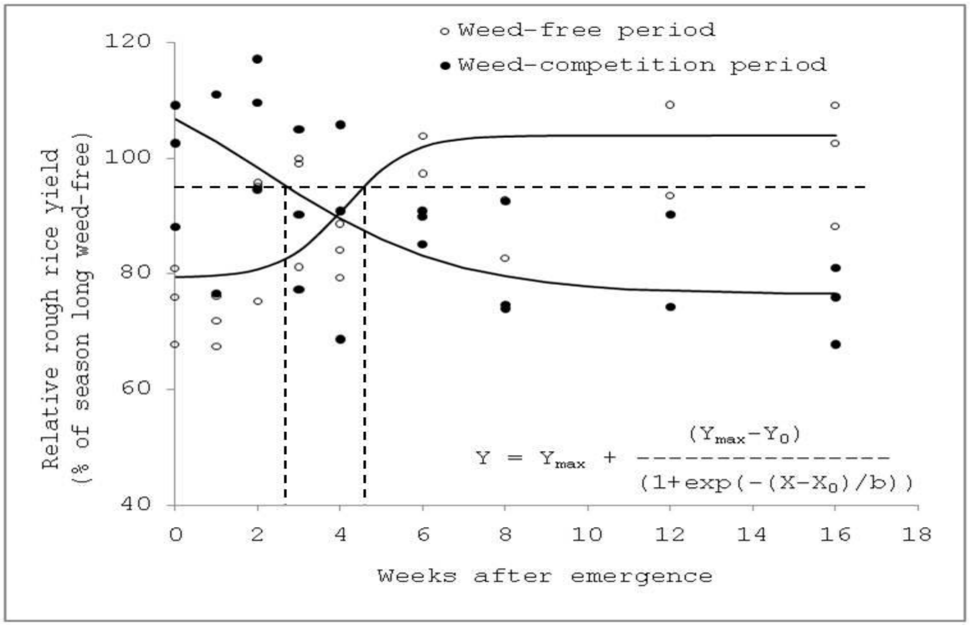

Figure 2.8 The effect of Texasweed interference and weed-free periods on relative rice yield in 2009. Equation 2.3, where Y and X are the relative rice yield and weeks after rice emergence (WAE), respectively. Parameter estimates and standard errors were Y_{max}=118.15(14.36), Y0=76.52(4.42), b=2.27 (0.80), and X0=2.22(1.14) for weed interference period; Y_{max}=103.96(2.92), Y0=79.34(4.00), b=-0.7693(0.32), and X0=4.12(0.31) for weed-free period.

yield loss; whereas, weed interference period of 20 to 80 days did not cause any yield reduction. The 18% yield reduction observed in season long weedy plots was attributed to adverse effect of shading from spreading dayflower on rice grain filling process. The weed plants in their studies did not emerge with the crop in the same field, but were grown in greenhouse and transplanted six to 11 days after rice emergence. The weeds in the above studies were also reported to grow taller and form a thick canopy above rice; however, the individual Texasweed plant did not form a thick and wide canopy in rice plots. The average canopy diameter at boot stage of rice was 22(±5) cm.

Previous work by Smith (1968, 1984) showed that broadleaf weeds reduces rice yield primarily by shading rice plants and reducing grain filling. However, present research demonstrates that in the case of Texasweed interference, rice yield is reduced much earlier. Both the Texasweed density and area of influence studies show that Texasweed interference reduces rice yield by affecting number of culms per unit area. Culms per unit area are a function of tillering, which begins when rice is at four- to five-leaf stage. The results indicate that substantial yield losses can occur if Texasweed control is delayed beyond 2 WAE. In addition, rice should be kept free of Texasweed until 5 to 6 WAE or permanent flood establishment.

End Notes

[1] Billy J. Williams, Louisiana State University Agricultural Center Weed Management specialist, 212 Macon Ridge Road Bldg. B, Winnsboro, LA 71295.

[2] Command® 3 ME herbicide label. FMC Corporation, Agricultural Products Group, 1735 Market Street, Philadelphia, PA 19103.

[3] Clincher® SF herbicide label. Dow AgroScience, Indianapolis, IN 46268.

[4] Ricestar HT® herbicide label. Bayer CropScience, P.O. Box 12014, 2 T.W. Alexander Dr., Research Triangle Park, NC 27709.

[5] Naturally dehisced seeds from mature Texasweed plants, cut and kept in shade at room temperature, were used in the experiment.

[6] Seed counter Model 850-3. International Marketing and Design Corporation, 13802 Lookout Rd. Suite 200 San Antonio, TX 78233.

[7] Regiment™ herbicide label. Valent Corporation, Walnut Creek, CA 94596.

[8] V-10142 experimental compound. Valent Corporation, Walnut Creek, CA 94596.

[9] Aim EC herbicide label. FMC Corporation, Agricultural Products Group, 1735 Market Street, Philadelphia, PA 19103.

[10] Roundup WeatherMax® herbicide label. Monsanto Co., St. Louis, MO 63167.

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Chapter 3

Effect of Shade on Texasweed (*Caperonia palustris*) Emergence, Growth and Reproduction

Introduction

Texasweed is an annual broadleaved plant belonging to Euphorbiaceae family (USDA 2007). It has existed in the Unites States as a wetland plant (Godfrey and Wooten 1981) and has not been a major problem in crop production, but lately it has become increasingly more common in rice, cotton, and soybean fields in the states of Texas, Louisiana, Mississippi, and Arkansas (Koger et al. 2004; Poston et al. 2007). Gianessi et al. (2002) reported Texasweed as the most troublesome broadleaf weed in Texas and Louisiana rice fields. Overall it was ranked 3rd and 5th most troublesome weed in the two states, respectively. Bennett (2003) also identified Texasweed as an emerging problem in Arkansas rice fields.

The shading effect of crop canopies is often an important component of integrated weed management systems (Keeley and Thullen 1978). Although response of Texasweed to shade has not been published, Texasweed can thrive under a thick hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh] canopy in the rice paddies at Louisiana State University Agricultural Center Northeast Research Station near St. Joseph, Louisiana. Hemp sesbania forms a very dense canopy and severely reduces the growth of rice crop and other plant species underneath (Smith 1968). Thus, the ability of Texasweed to grow and reproduce under low light conditions found under a hemp sesbania canopy can have implications on its management in the crops that rely on crop canopy cover for mid- and late-season weed control. However, crops differ in the time and rate of canopy closure (Caton et al. 2002; Murdock et al. 1986). Crops with rapid early season growth are more competitive than those with a long period of slow growth early in the season (Keeley and Thullen 1978). The relative time of emergence and rate of canopy formation are, thus, the important factors in determining the competitiveness between the crop and a weed.

Murdock et al. (1986) reported that regardless of row spacing and cultivar, photosynthetically active radiation (PAR) at soil surface near a soybean plant was reduced by 50, 70, and 90% at 23, 29, and 40 days after planting, respectively. The days required to reduce PAR by these percentages at a point midway between two rows was dependent on the row spacing; the estimated values 90% PAR reduction in 61 cm and 91 cm row spacing were 53 and 63 days after planting, respectively. Thus row spacing affects the time to beginning of the canopy closure, i.e. the time when it starts to shade the middle of the rows. Once a canopy starts to close, regardless of the row spacing, the available PAR reduces from 50 to 90% in about 10 to 15 days.

Dingkuhn et al. (1999) reported that 30 and 45 days after planting (DAP) 'Bouke 189', a semi-dwarf indica type rice cultivar, caused 16 and 54% reduction in the diffused PAR reaching the soil surface. In comparision, the reduction in PAR by 'Moroberekan', a tall japonica type cultivar, was 18 and 56%, respectively. No rice cultivar intercepted more than 20% of the PAR at 30 DAP, and PAR availability increased sharply towards the top of the canopy. At 64 DAP, the short-statured and erect leaved 'Bouake 189' caused only 25% PAR reduction at a point 40 cm above the ground; the reduction caused by other cultivars ranged between 50 and 70%.

The weed suppressing effect of a crop canopy is a result of shading, which can reduce weed emergence and growth (Caton et al. 1997; Caton et al. 2001; Gibson et al. 2001; Jha and Norsworthy 2009). Plants differ in their photosynthetic efficiency and response to shade. Some plant species can escape the adverse effects of shade by increasing their height and shoot/root partitioning (Caton et al. 1997) and/or by increasing leaf area in proportion to the total plant tissue (Patterson 1979). Therefore, the successful utilization of crop characteristics for weed management requires an understanding of the response by the weeds to alterations in the environment.

The knowledge of the Texasweed response to shade can be used in ecophysiological models developed for analyzing integrated weed management strategies in various crops. Therefore, experiments were planned to evaluate the effect of shade on Texasweed emergence, growth, and reproduction. A review of the literature on plant response to shade revealed that, in most of the experiments, the plants were kept under constant shade levels for the entire duration of the experiment (Boyd and Murray 1982; Jones and Griffin 2010; Santos et al. 1997; Wiggans 1959). However, a constant shade level does not represent the shade conditions under a real crop canopy where PAR decreases gradually as the crop grows. Therefore, an attempt was made to simulate the shade conditions of gradually increasing shade under a crop canopy by exposing plants to increasing shade levels before reaching the desired final shade level. Thus, the objectives of the study were:

1. To study the effect of shade on Texasweed emergence and growth.
2. To compare effect of the shade establishment methods- gradual transfer and direct transfer of plants to a shade level.
3. To develop a predictive model for Texasweed growth based on initial and final shade levels.

Materials and Methods

General. Research was conducted in 2007 and 2008 at the Louisiana State University Agricultural Center’s Northeast Research Station near St. Joseph, Louisiana using Sharkey clay (very fine, montmorillonitic, nonacid, Vertic Haplaquept) with pH 6.1 and 2.1% organic matter. The soil was taken from a field with no Texasweed infestation history. The field was fallow for approximately 18 months before the soil was used in 2007 and no residual herbicide was applied to it during this period. Naturally dehisced seeds from

Texasweed plants, cut and kept in shade at room temperature, were used in the study. The seeds thus obtained were of varying size and color. The seed color varied from light grey to dark brown. In general, the light seed color was associated with smaller size and lighter weight. The actual cause of the color difference is not known; however, it could be due to maturity difference between the seeds at the time when Texasweed plants were cut for seed collection. The size difference was minimized by sieving[2], which provided seeds of similar size. The seeds were then divided into two groups based on their color: dark brown and grey colored seeds (Figure 3.1a).

Shade levels of 0, 30, 50, 70, and 90% were achieved using 1.8 m x 1.8 m x 1.8 m tents (Figure 3.1b) built using one inch diameter PVC pipe and polypropylene fabric[1], shade-cloth. Shade intensities inside the tents, expressed as percent of the PAR outside the tents, were confirmed within three percent using an AccuPAR Linear PAR Ceptometer[3]. Temperatures inside the shade enclosures were monitored on an hourly basis using WatchDog B-Series button logger[4] and were found to be within ±2°C of the ambient air temperature outside (data not presented).

Texasweed Emergence Study. The emergence study was conducted in 2007 and 2008 under field conditions and involved planting of 75 Texasweed seeds in 3 L plastic pots filled with Sharky clay soil (Figure 3.1d). Koger et al. (2004) reported maximum Texasweed emergence from 1-cm depth; therefore, seeds were planted approximately 1 cm deep. Treatments consisted of five shade levels: 0, 30, 50, 70, and 90%, and two seed types, dark brown and grey colored seeds. The experiment was laid out as a split-plot in a completely randomized design with four replications. The whole plot treatments were the five shade levels and the sub-plot treatments were the two seed types: dark brown and grey colored seeds. Four pots per enclosures were used for each treatment combination. Maximum Texasweed emergence occurs when seeds are watered at 5 days interval (Koger et al. 2004); therefore, pots were watered with equal amount of water at the beginning of the experiment and at weekly intervals thereafter. Texasweed emergence was recorded weekly for one month and percent emergence was calculated by dividing total emergence count by the number of seeds planted.

Figure 3.1 (a) dark brown and grey colored Texasweed seeds used in the emergence experiments; (b) a 50% shade tent; (c) layout of the experiment; (d) pots used in the experiment.

Data were analyzed using MIXED procedure of SAS (SAS 2003) to test the effect of shade and seed type on Texasweed emergence. Year and year by shade interaction were considered random effects. LSMEANS were used for comparision and Tukey’s test at P=0.05 was used for the mean separation. Letter groupings were generated using the PDMIX800 macro in SAS (Saxton 1998).

Texasweed Growth and Reproduction Study. The growth response study was conducted in 2007 and 2008 using potted plants under the field conditions (Figure 3.1c). Pots and the soil used for this study were same as previously described for emergence study. Five Texasweed seeds were planted per pot in 2007. Three uniform sized plants were retained per pot at first thinning, 3 days after emergence, which was considered 0 days after the study initiation (DAI). To get plants of greater size and vigor uniformity, 10 Texasweed seeds per pot were planted in 2010. To get the plants of a uniform age, Texasweed plants emerging after 0 DAI were removed from the pots. At 28 days of emergence when the Texasweed plants were two to three leaf stage, they were further thinned to one plant per pot. The pots were kept free of other unwanted plants by regular hand weeding.

The study was a randomized complete block design with three replications. Treatments for the experiment were the different shade regimes obtained by transferring the potted plants to increasing shade levels every 14 days (Table 3.1). For the treatments with same starting shade level (Table 3.1), the pots were not assigned to individual treatments at the time of study initiation but were pooled together as a group. At the time of each transfer, some of the pots from each group were retained in the current shade level and others were transferred, as a group, to the next shade level. The pots were randomized and spaced at the time of each transfer to avoid close contact with other plants and plnat competition for light. The process was repeated every 14 days until 56 DAI. Thus, all treatments were not established until 56 DAI, which was the final transfer of pots.

To distinguish the pots already present in a tent from those coming from the lower shade levels, the pots were marked using small plastic stakes (Figure 3.1d). Current shade level was added to the stakes at the time of each transfer. Once transferred to the highest shade level of the respective treatments, Texasweed grew undisturbed until 100 DAI.

Table 3.1 Treatments for the study on effect of shade on Texasweed growth and reproduction.[a]

Treatment (Shade regime)	Starting shade level (%)	Days after study initiation (DAI)				Final shade level (%)
		14	28	42	56	
		--shade level (%) transferred to--				
T1	0	*	*	*	*	0
T2	0	30	*	*	*	30
T3	0	30	50	*	*	50
T4	0	30	50	70	*	70
T5	0	30	50	70	90	90
T6	30	*	*	*	*	30
T7	30	50	*	*	*	50
T8	30	50	70	*	*	70
T9	30	50	70	90	*	90
T10	50	*	*	*	*	50
T11	50	70	*	*	*	70
T12	50	70	90	*	*	90
T13	70	*	*	*	*	70
T14	70	90	*	*	*	90
T15	90	*	*	*	*	90

[a] Texasweed plants started growing in the starting shade level; every 14 days, some of the plants were transferred to the next higher shade level ultimately reaching the final shade level.

[*] Final shade level already achieved, no transfer required.

Destructive plant samples were collected at 14 day intervals i.e. just before each transfer event. This was achieved by randomly removing several plants from each transfer group in each shade tent. Data on plant height, above ground dry matter, and leaf area were recorded. Height was measured from base of the plant to the tip of the third leaf from the top. The third leaf from the top was largest leaf on the plant and provided maximum plant height. Plants were separated into leaves and stem and total leaf area per plant was measured using LICOR LI-3050A conveyer leaf area meter[5]. Leaves and stems were dried at 60°C to a constant weight using a ventilated oven. Data on number of fruits i.e. capsules per plant were also recorded at the time of last observation (100 DAI). Total dry weight per plant was obtained as the sum of leaf and stem dry weights. Specific leaf area (SLA) was calculated by dividing total leaf area by leaf dry weight and percent leaf biomass was calculated by dividing leaf dry weight by total dry weight.

Growth and fruit production data were analyzed for treatment differences using ANOVA. Variance for height and total dry matter per plant data increased a function of mean; therefore, a square root ($Y=\sqrt{X}$) was performed to homogenize the variance. Data for SLA were subjected to log transformation ($Y=\log(X)$) to normalize the residuals. The data were analyzed separately for each observation date (DAI) because number of treatments were not equal at all the observation dates, and also because the differences between treatments at each DAI were more important than changes over time. MIXED procedure of SAS (SAS 2003) was used to get Type III test for fixed effects. Year and replication within a year were considered random effects. LSMEANS were used for comparision and Tukey's test at $P=0.05$ was used for the mean separation. Letter groupings were generated using the PDMIX800 macro in SAS (Saxton 1998). Linear and quadratic contrasts were also constructed, wherever needed, to study the trend in the response.

The total dry matter data were also subjected to regression analysis to model the response variable as a function of time (DAI), and the initial and current shade levels. Current shade level is the shade level at the time of data collection. To increase the applicability of the results across various environments, the total dry weight data were converted to percent of the total dry weight observed in 0% shade at 100 DAI. In the cases where treatments were not distinguishable from each other at a given DAI the common data collected for that group was used for each treatment. A graphical observation of the data showed sigmoid shaped trend. Therefore, NLMIXED procedure of SAS (SAS 2003) was used to fit nonlinear growth models to the data for each of the 15 treatments separately. The models with both year and replication within year as random effects failed to converge. The parameter estimate for replication random effect as obtained using MIXED procedure of

SAS for these variables was also approximately zero. Therefore, only year was used as a random effect. Null-model likelihood ratio tests for nested models and Akaike's information criteria (AIC) values for unrelated models were used to compare different models and the criteria of better fit and parsimony was used to select a final model. A three parameter logistic model (Equation 3.1) provided best fit for all the shade regimes.

$$Y = Y_{max}/(1+\exp(-(X-X_0)/b)) \qquad \text{[Equation 3.1]}$$

Where, Y is the response, and X is days after study initiation (DAI), Y_{max} is the upper asymptote, X_0 (inflection point) is the time at which Y is 50% of the Y_{max}, and b is the slope at the inflection point.

The parameters thus obtained for each of the treatments were again regressed against the starting and the current shade levels. Null-model likelihood ratio tests and AIC values were again used to compare different models and the criteria of better fit and parsimony was used to select a final model for each parameter. The empirical models for the parameters thus obtained were then incorporated into a composite model developed for predicting response as a function of time (DAI), starting shade level and current shade level.

Results and Discussion

Effect of Shade on Texasweed Emergence. Shade did not affect Texasweed emergence (data not shown). Seed type, however, had a significant effect on emergence. Averaged across the shade levels, Texasweed emergence was 60 and 27% for the dark brown and grey seeds, respectively. The difference in emergence between dark brown and grey seeds indicates maturity difference between the two seed types. Laboratory studies under controlled conditions are required to study the viability and germination of the two seed types.

Effect of Shade on Texasweed Growth. Texasweed height was affected by shade. Texasweed in 30 and 50% shade at 14 DAI, were smaller than those in full sun. Quadratic contrasts at 28 DAI and onwards also indicated that

Texasweed height, at a given DAI, increased with increasing shade level up to 70% and then decreased. After 28 DAI, 70% shade resulted in taller plants; the height was increased 15 to 21% compared with 0% shade.

Table 3.2 Effect of constant shade on Texasweed height and dry weight expressed as percent of control.[a]

Shade level (%)	Days after study initiation (DAI)					
	14	28	42	56	70	100
	Height[b,c,d]					
0(Control)	100 a	100 b	100 b	100 b	100 b	100 b
30	84 b	98 b	100 b	103 b	105 b	106 b
50	86 b	102 b	101 b	104 b	106 b	106 b
70	104 a	116 a	116 a	118 a	121 a	115 a
90	84 b	97 b	94 b	96 b	90 c	89 c
	P-values					
Linear contrast	0.0156	0.0756	0.4386	0.3314	<0.3835	0.0091
Quadratic contrast	0.0516	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Dry weight[b,c,e]					
0(Control)	100 a	100 a	100 a	100 a	100 a	100 a
30	42 b	62 b	77 b	80 b	86 a	88 a
50	53 b	58 b	81 b	74 bc	66 b	69 b
70	44 b	51 b	68 b	61 c	53 c	53 c
90	14 c	10 c	11 c	10 d	12 d	10 d
	P-values					
Linear contrast	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Quadratic contrast	0.9273	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a] Texasweed plants (pots) were in the given shade levels for the entire duration of the experiment and were not transferred from any other shade level.

[b] The values in each column are expressed as percent of control; however, mean separation was done using the Y= √X transformed data.

[c] Means followed by a common letter within each column are not significantly different based on Tukey’s test at P=0.05.

[d] The actual values for height in control were 19.2, 23.6, 33.8, 41.5, 56.8 and 67.1 cm at 14, 28, 42, 56, 70 and 100 DAI, respectively.

[e] The actual values for dry weight per plant in control were 0.329, 1.106, 2.277, 5.491, 9.816 and 11.739 g at 14, 28, 42, 56, 70 and 100 DAI, respectively.

Contrasts analysis carried out to study the effect of starting shade level indicated an impact of starting shade on height (Table 3.3). For 50% shade, plant height decreased with an increase in starting shade level;

whereas, for 70 and 90% shade levels, height increased as the starting shade level increased. The above trends were observed up to 42 DAI for 30 and 50% shade levels, and up to 70 DAI for 70% shade level. The effect of starting shade level was most prominent on the plants in 90% shade. The Tukey's test and the linear contrasts show a decrease in plant height with increasing starting shade level at all observation dates.

Data in Table 3.2 show dry matter reduction in shaded plants. The linear and quadratic contrasts indicated that dry matter production decreased as a function of increasing shade level. These differences appeared as early as 14 DAI. At the end of the experiment, 50, 70, and 90% shade caused 31, 47, and 90% reduction in dry matter per plants, respectively (Table 3.2).

Contrast analysis indicated an effect of starting shade on Texasweed dry matter production (Table 3.4). At 28 and 42 DAI, plants coming from 0% shade produced higher biomass than those growing in 30% shade. These differences, however, decreased as time progressed. The differences between directly and gradually transferred plants appeared at 28, 70, and 70 DAI for 90, 70, and 50% shades, respectively, and became more prominent with time.

The magnitude of shade had a very strong effect on specific leaf area (SLA) (Table 3.5). Both Tukey's test and the contrast analysis suggested an increase in SLA due to increasing shade level; the increase was greater for shades above 50% at all the observation dates. The SLA in 70% shade was approximately twice that observed in no shade; the increase in case of 90% shade was more than double. A difference in SLA between plants transferred directly and gradually to a given shade level was observed (Table 3.6). SLA increased as the starting shade level increased. The differences remained conspicuous for only two weeks after the transfer events and started to disappear with time.

Table 3.3 Texasweed height (cm) as affected by direct and gradual transfer to a given shade level.[a]

Starting shade level (%)	Current shade level (%)				
	0	30	50	70	90
	28 DAI[b,c]				
0	23.4	27.3 a	.	.	.
30		22.7 b	23.6 a	.	.
50			24.5 a	27.9 a	.
70				31.5 a	31.1 a
90					22.0 b
Linear Contrast (P-value)		<0.0001	0.4538	0.0058	<0.0001
	42 DAI[b,c]				
0	33.8	37.3 a	39.3 a	.	.
30		33.6 a	34.3 a	42.1 a	.
50			34.6 a	44.6 a	40.0 a
70				45.3 a	38.3 a
90					30.0 b
Linear Contrast (P-value)		0.0500	0.0041	0.0843	<0.0001
	56 DAI[b,c]				
0	41.5	46.8 a	47.8 a	55.7 a	.
30		44.5 a	45.0 a	61.8 a	57.1 a
50			44.7 a	57.7 a	54.6 a
70				57.6 a	51.0 a
90					38.1 b
Linear Contrast (P-value)		0.3292	0.2109	0.9527	<0.0001
	70 DAI[b,c]				
0	56.7	64.7 a	66.3 a	75.9 a	74.0 a
30		62.8 a	64.8 a	74.8 a	73.0 a
50			63.7 a	80.7 a	66.6 ab
70				82.4 a	57.4 b
90					46.0 c
Linear Contrast (P-value)		0.4838	0.3735	0.0074	<0.0001
	100 DAI[b,c]				
0	66.8	74.8 a	77.8 a	85.4 a	80.3 a
30		75.5 a	75.9 a	85.7 a	79.4 a
50			74.7 a	92.0 a	70.0 ab
70				88.2 a	64.4 b
90					53.5 c
Linear Contrast (P-value)		0.8175	0.3066	0.0959	<0.0001

[a] Texasweed plants started growing in the starting shade level; every 14 days, some of the plants were transferred to the next higher shade level ultimately reaching the final shade level. The current shade level is the shade level at the time of data collection i.e. just before the transfer.

[b] For each response variable, the values in each column are retransformed values; mean separation was done using the $Y= \sqrt{X}$ transformed data.

[c] Means followed by a common letter within each column are not significantly different based on Tukey's test at P=0.05.

Table 3.4 Texasweed dry weight (g/plant) as affected by direct and gradual transfer to a given shade level.[a]

Starting shade level (%)	Current shade level(%)				
	0	30	50	70	90
	28 DAI[b]				
0	1.100	0.959 a	.	.	.
30		0.680 b	0.653 a	.	.
50			0.644 a	0.547 a	.
70				0.557 a	0.318 a
90					0.111 b
Linear Contrast (P-value)		<0.0001	0.8376	0.8222	<0.0001
	42 DAI[b]				
0	2.277	2.080 a	1.735 a	.	.
30		1.762 a	1.820 a	1.529 a	.
50			1.852 a	1.659 a	0.958 a
70				1.558 a	0.687 b
90					0.257 c
Linear Contrast (P-value)		0.0045	0.1895	0.7402	<0.0001
	56 DAI[b]				
0	5.491	4.736 a	4.515 a	4.194 a	.
30		4.397 a	4.225 a	4.172 a	1.970 a
50			4.063 a	3.640 a	1.760 a
70				3.330 a	1.345 a
90					0.566 b
Linear Contrast (P-value)		0.2796	0.1219	0.6817	<0.0001
	70 DAI[b]				
0	9.824	8.326 a	7.950 a	6.357 a	4.191 a
30		8.403 a	7.479 a	6.190 a	3.364 a
50			6.520 a	5.487 a	2.417 b
70				5.179 a	2.008 b
90					1.147 c
Linear Contrast (P-value)		0.8606	0.0008	0.0002	<0.0001
	100 DAI[b]				
0	11.747	10.247 a	9.175 a	7.451 a	4.966 a
30		10.394 a	8.841 a	7.069 ab	3.723 b
50			8.082 a	6.646 ab	2.692 c
70				6.244 b	2.166 c
90					1.121 d
Linear Contrast (P-value)		0.7416	0.0065	0.0004	<0.0001

[a] Texasweed plants started growing in the starting shade level; every 14 days, some of the plants were transferred to the next higher shade level ultimately reaching the final shade level. The current shade level is the shade level at the time of data collection i.e. just before the transfer.

[b] Means followed by a common letter within each column are not significantly different based on Tukey’s test at P=0.05.

Table 3.5 Effect of constant shade on specific leaf area (SLA) and percent leaf biomass of Texasweed plants.[a]

Shade level (%)	Days after study initiation (DAI)					
	14	28	42	56	70	100
	-------------------- Specific leaf area (cm^2/g)[b,c] -----------------					
0	167 c	169 e	162 d	150 e	135 e	129 d
30	190 b	206 d	188 c	174 d	163 d	158 c
50	192 b	245 c	209 c	204 c	195 c	184 bc
70	318 a	370 b	322 b	292 b	236 b	211 b
90	348 a	515 a	498 a	397 a	332 a	286 a
	------------------------ P-values ----------------------					
Linear contrast	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Quadratic contrast	0.0007	<0.0001	<0.0001	<0.0001	0.0157	0.1929
	------------------- Percent leaf biomass (%)[c] -----------------					
0	62 b	54 b	49 d	45 c	43 c	65 a
30	67 a	62 a	56 b	52 b	45 bc	56 b
50	69 a	69 a	58 b	53 b	47 bc	56 b
70	70 a	68 a	60 ab	55 b	52 ab	51 bc
90	68 a	65 a	63 a	63 a	58 a	47 c
	------------------------ P-values ----------------------					
Linear contrast	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Quadratic contrast	<0.0001	<0.0001	0.0927	0.2813	0.0760	0.1184

[a] Texasweed plants (pots) were in the given shade levels for the entire duration of the experiment and were not transferred from any other shade level.

[b] Values in each column are the retransformed values; mean separation was done using the Y= log(X) transformed data.

[c] Means followed by a common letter within each column are not significantly different based on Tukey's test at P=0.05.

The results show that until 70 DAI, the shaded plants had a higher percent leaf biomass than those grown in full sun (Table 3.5). As determined by the Tukey's test, the differences among the shade levels were not significant until 42 DAI when plants in 90% shade had higher percent leaf biomass than those in 30 and 50% shade. The plants in 30, 50, and 70% shade did not differ at any observation date. Contrast analysis showed a gradual increase in percent leaf biomass due to increasing shade (Table 3.5). However, at 100 DAI, Texasweed in control treatment had the highest percent leaf biomass. Percent leaf biomass of the plants transferred gradually and directly to a shade level was not characteristically different. Significant differences were observed only in 90% shade at 100 DAI (Table 3.7).

Table 3.6 Texasweed specific leaf area (cm^2/g) as affected by direct and gradual transfer to a given shade level.[a]

Starting shade level (%)	Current shade level (%)				
	0	30	50	70	90
	------------------------- 28 DAI[b,c] -------------------------				
0	169	191 a	.	.	.
30		206 a	230 a	.	.
50			245 a	334 a	.
70				370 a	489 a
90					515 a
Linear Contrast (P-value)		0.0413	0.0764	0.0067	0.2369
	------------------------- 42 DAI[b,c] -------------------------				
0	162	178 a	213 a	.	.
30		188 a	208 a	280 b	.
50			209 a	314 ab	363 b
70				322 a	456 a
90					498 a
Linear Contrast (P-value)		0.1841	0.5899	0.0003	<0.0001
	------------------------- 56 DAI[b,c] -------------------------				
0	150	174 a	210 a	257 b	.
30		174 a	196 a	272 ab	313 b
50			204 a	282 ab	367 a
70				292 a	406 a
90					397 a
Linear Contrast (P-value)		0.9734	0.3220	0.0002	<0.0001
	------------------------- 70 DAI[b,c] -------------------------				
0	135	156 a	202 a	232 a	260 b
30		163 a	196 a	256 a	298 ab
50			195 a	256 a	287 ab
70				236 a	332 a
90					332 a
Linear Contrast (P-value)		0.3909	0.5114	0.7356	<0.0001
	------------------------- 100 DAI[b,c] -------------------------				
0	129	160 a	192 a	214 a	242 b
30		158 a	184 a	239 a	255 ab
50			184 a	214 a	257 ab
70				211 a	286 a
90					286 a
Linear Contrast (P-value)		0.7245	0.3715	0.1735	<0.0001

[a] Texasweed plants started growing in the starting shade level; every 14 days, some of the plants were transferred to the next higher shade level ultimately reaching the final shade level. The current shade level is the shade level at the time of data collection i.e. just before the transfer.

[b] Values in each column are the retransformed values; mean separation was done using the Y=log(X) transformed data.

[c] Means followed by a common letter within each column are not significantly different based on Tukey's test at P=0.05.

Table 3.7 Texasweed percent leaf biomass as affected by direct and gradual transfer to a given shade level.[a]

Starting shade level (%)	Current shade level (%)				
	0	30	50	70	90
	28 DAI[b]				
0	54	58 a	.	.	.
30		62 a	66 a	.	.
50			69 a	67 a	.
70				68 a	67 a
90					65 a
Linear Contrast (P-value)		<0.0063	0.0438	0.0058	<0.0001
	42 DAI[b]				
0	49	55 a	56 a	.	.
30		56 a	58 a	63 a	.
50			58 a	60 a	64 a
70				60 a	64 a
90					63 a
Linear Contrast (P-value)		0.6341	0.0730	0.0083	0.9027
	56 DAI[b]				
0	45	50 a	49 a	55 a	.
30		52 a	50 a	55 a	60 a
50			53 a	54 a	60 a
70				55 a	63 a
90					63 a
Linear Contrast (P-value)		0.0813	0.0934	0.6317	0.0224
	70 DAI[b]				
0	43	46 a	46 a	50 a	56 a
30		45 a	47 a	54 a	57 a
50			47 a	52 a	57 a
70				52 a	58 a
90					58 a
Linear Contrast (P-value)		0.8434	0.8132	0.8835	0.1197
	100 DAI[b]				
0	65	54 a	59 a	50 a	44 b
30		56 a	58 a	49 a	46 ab
50			56 a	49 a	49 ab
70				51 a	52 a
90					47 ab
Linear Contrast (P-value)		0.3126	0.1365	0.5555	0.0008

[a] Texasweed plants started growing in the starting shade level; every 14 days, some of the plants were transferred to the next higher shade level ultimately reaching the final shade level. The current shade level is the shade level at the time of data collection i.e. just before the transfer.

[b] Means followed by a common letter within each column are not significantly different based on Tukey's test at P=0.05.

Observations in terms of Texasweed SLA and percent leaf biomass are similar to those observed in other plant species. *Ammannia* spp. increased SLA and percent leaf biomass in response to a decrease in photosynthetic photon flux density (PPFD) (Gibson et al. 2001). Patterson (1979) also reported similar response to shade in many terrestrial and aquatic plants. Texasweed seems to mitigate the adverse effect of shade by increasing SLA and percent leaf biomass. These two responses appears to be a strategy for efficient allocation of fresh biomass for light capture and carbohydrate synthesis, which can be used for height increase until the plant rises above the crop canopy.

The model developed for Texasweed dry matter reduction as a function of time, and starting and current shade levels (Equation 3.2) can be used in conjunction with the knowledge of rate and extent of canopy formation to make management decisions.

$$Y = Y_{max}/(1+exp(-(X-X_0)/b)) \qquad \text{[Equation 3.2]}$$

$$Y_{max} = 97.58 - 0.07460*IS - 0.00207*IS^2 + 0.05334*CS - 0.00818*CS^2$$

$$b = 9.99$$

$$X_0 = 56.42$$

Where, Y is the response, and X is days after study initiation (DAI), Y_{max} is the upper asymptote, X_0 (inflection point) is the time at which Y is 50% of the Y_{max}, b is the slope at the inflection point, IS is the initial shade (%) and CS is the current shade (%).

Regardless of the shade at the time of Texasweed emergence, if a crop canopy is able to cause more than 90% reduction in PAR within 70 days after planting, Texasweed dry matter production will be reduced by 65 to 90% (Figure 3.2). In crops like soybean where the shade in the middle of two rows increases to more than 90% in 50 to 60 days after planting (Murdock et al. 1986), the dry matter production by Texasweed plants particularly those emerging late can be severely reduced. The model also suggests that in crop canopies that can only cause a maximum shade level of 50 or 70%, Texasweed biomass reduction will be no more than 30 and 60%, respectively (Figure 3.2b and 3.2c). The findings of the present research can also be applied to Texasweed management in drill-seeded rice. Rice crop at 30 days after planting causes less than 20% reduction in the PAR reaching the ground; the reduction in PAR caused at 64 days after planting is 50 to 70% (Dingkuhn et al. 1999). The PAR availability also increases sharply near the top of the canopy. Thus, it can be expected that Texasweed plants emerging before permanent flood establishment in drill-seeded rice will experience no more than 50% shade at the soil surface. By the time of canopy closure, Texasweed plants emerging with the crop would be tall enough to avoid any growth reduction. As discussed earlier, a 15 to 20% height increase was observed in 70% shade (Table 3.2). Even 90% shade was not able to cause more than 16% reduction in Texasweed height. Therefore, the Texasweed plants emerging late may also grow above the crop canopy, depending upon the crop height, and offset the reduction in dry matter production caused by shade early in the season. Caton et al. (1999) suggested that in dense crop-weed canopies relative plant height strongly affects competitive outcome. Caton et al. (1997) noted that increased height and shoot:root ratio of *Ammannia* spp. under shaded conditions might allow it to escape shading by rice crop. Gibson et al. (2001) also concluded that owing to purple ammannia's ability to withstand and recover from shade, its control in rice through light manipulation alone may not be possible.

Effect of Shade on Texasweed Reproduction. Texasweed plants in all the shade levels were able to flower and set fruits. Fruit production was impacted by the final but not the starting shade level (Figure 3.3). Compared with shaded plants, the plants in full sun produced higher number of fruits per plant. Fruit production in 90% shade was reduced by approximately 90% as compared with the full sun. Texasweed fruit production in 30, 50 and 70% shade was similar.

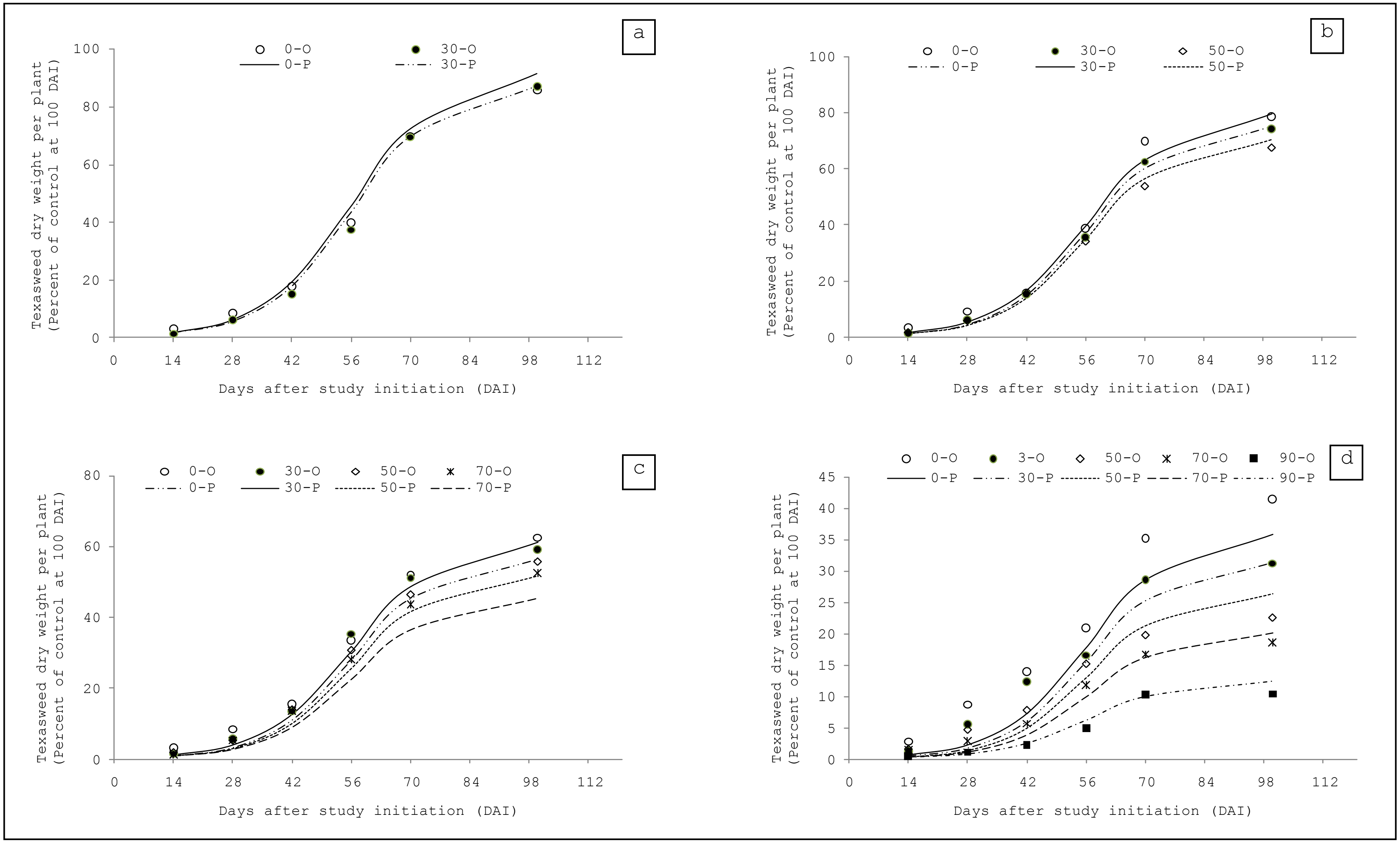

Figure 3.2 Texasweed dry matter per plant (% of full sun at 100 DAI): (a) 30% final shade; (b) 50% final shade; (c) 70% final shade; (d) 90% final shade. Symbols represent the observed (O) values, lines represent the value predicted (P) by the final prediction model (Equation 3.2); the numbers 0, 30, 50, 70 and 90 in the legend entries represent the starting shade levels.

The results of this research indicated that Texasweed growth can be reduced by shade, but the reduction in PAR must occur early in the season and needs to be of 90% or higher magnitude to stop Texasweed from emerging above the crop canopy. However, owing to the partial shade of < 50% and a sharp increase in available PAR towards the canopy top (Dingkuhn et al. 1999), a rice canopy may never be able to severely affect Texasweed growth. Although, fruit production in shade is reduced, Texasweed has the ability to reproduce even in 90% shade, which can pose a challenge in subsequent crops.

Growth differences between plants transferred directly and gradually to a given shade level suggest that weed growth under a real crop canopy, where shade increases gradually, will be different than under constant shade. Thus, studies where plants are gradually exposed to increasing shade levels are better at modeling weed growth under a crop canopy.

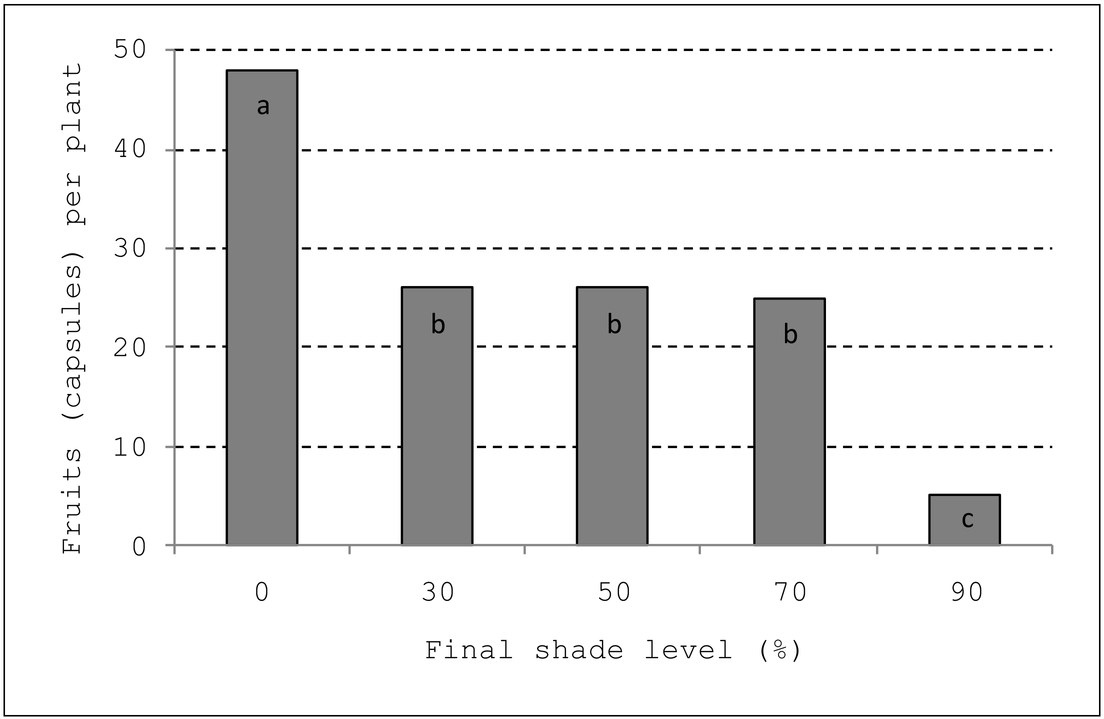

Figure 3.3 Effect of shade on fruit (capsule) production by Texasweed plants; values in each final shade level are averaged across the starting shade levels. Means followed by a common letter within each column are not significantly different based on Tukey’s test at P=0.05.

End Notes

[1] DeWitt Company, 905 S. Kings Highway, Sikeston, MO 63801.

[2] Seive No C 1/12” Round (Commercial). Seedburo Equipment Company, 1022 W Jackson Blvd. Chicago, IL 60607.

[3] Decagon Devices, Inc., 950 NE Nelson Court, Pullman, WA 99163.

[4] Spectrum Technologies, Inc. 12360 South Industrial Dr. East - Plainfield, Illinois 60585.

[5] LI-COR, Inc., 4421 Superior Street, P.O. Box 4425, Lincoln, Nebraska 68504.

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Chapter 4

Effect of Flood Depth on Texasweed (*Caperonia palustris*) Growth and Reproduction

Introduction

Texasweed [*Caperonia palustris* (L.) St. Hil.] is an annual broadleaved plant belonging to the Euphorbiaceae family (USDA 2007). It has existed in the Unites States as a wetland plant (Godfrey and Wooten 1981), but historically has not been a major problem in crop production. Lately it has become increasingly common in rice, cotton, and soybean fields in the states of Texas, Louisiana, Mississippi, and Arkansas (Koger et al. 2004; Poston et al. 2007). Gianessi et al. (2002) reported Texasweed as one of the most troublesome broadleaf weed in Texas and Louisiana rice production systems. Overall it was ranked 3rd and 5th most troublesome weed in the rice production systems of the two states, respectively. Bennett (2003) also identified Texasweed as an emerging problem in Arkansas rice fields.

Cultural practices like tillage, crop rotation, variety selection, seed rate, row spacing and orientation are generally based on agronomic considerations but have a bearing on crop-weed interaction, and can be manipulated to tilt the crop-weed interaction in the favor of crops (Roa 2000). Any adjustment or modification to the general management of a crop or cropping system that contributes to the regulation of the weed population, and reduces the negative impact of weeds on crop production is known as cultural weed control (Bastiaans et al. 2008). Cultural methods of weed control can form an important component of weed management programs in crop production systems (Buhler 1996; Mortensen et al. 2000; Rao 2000). Successful utilization of the cultural methods of weed control requires a deep understanding of the principles of weed biology and ecology (Maxwell and Donovan 2007).

Establishment of permanent flood is an important cultural practice for weed management in rice cultures (Mortimer et al. 1999; Williams et al. 2001; Bouman et al. 2007). Flooding can affect both weed emergence and growth. Smith and Fox (1973) reported reduced emergence and growth of barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster], hemp sesbania [*Sesbania herbacea* (Mill.) McVaugh], northern jointvetch [*Aeschynomene virginica* (L.) Britton, Sterns & Poggenb.] and red rice (*Oryza sativa* L.) under continuous soil submergence. Hirase and Molin (2002) reported no hemp sesbania emergence in 5 and 10 cm deep water; water depth of even 1 cm reduced the germination by 84%. Submergence of two leaf stage hemp sesbania plants in the same study caused significant growth reduction. Williams et al. (1990) reported strong suppression of barnyardgrass, early watergrass [*Echinochloa oryzoides* (Ard.) Fritsch] and variable flatsedge (*Cyperus difformis* L.) by deep flood, ≤ 20 cm. Sahid and Hossain (1995) also reported complete control of seedling barnyardgrass by 15 cm deep flood. Benvenuti et al. (2004) reported complete inhibition of Chinese sprangletop [*Leptochloa chinensis* (L.) Nees] emergence in floods deeper than 6 cm. Seaman (1983) indentified grass weed suppression as the primary reason for popularization of water-seeding of rice in California in late 1920s and early 1930s. Red rice suppression in water seeding system is cited as the reason for popularity of this system in south Louisiana (Linscombe 1999).

Flooding inhibits weed growth by reducing oxygen availability to the roots (Vartapetian and Jackson 1997). Weeds differ in their ability to tolerate anaerobic conditions (Stoecker et al. 1995) and many weeds like alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.], barnyardgrass, creeping rivergrass [*Echinochloa polystachya* (Kunth) Hitchc.], ducksalad [*Heteranthera limosa* (Sw.) Willd.], hemp sesbania, ludwigia [*Ludwigia* *hyssopifolia* (G. Don) Exell apud A.R. Fernandes], palmleaf morningglory (*Ipomoea wrightii* A. Gray), purple ammannia (*Ammannia coccinea* Rothb.), red rice are adapted to flooded conditions in the rice paddies (Bottoms 2009; Gealy 1998; Hirase and Molin 2002; Sahid and Hossain 1995; Smith and Fox 1973; Yu et al. 2007).

Plants can mitigate the adverse effects of hypoxia and anoxia by adjusting dry matter partitioning between shoot and root (Nakayama et al. 2009) and/or by forming aerenchyma in their submerged parts (Evans 2004; Shimamura et al. 2003; Solaiman et al. 2007; Thomas et al. 2005). Monocot plants like rice (Kawai et al. 1998) and maize (*Zea mays* L.) (Lenochová et al. 2009) produce cortical aerenchyma in their roots, which provides low resistance pathway for oxygen transport.

In dicot plants secondary aerenchyma, phellem, developed in the phellogen region derived from pericycle cells replaces the function of cortical aerenchyma as an effective stress avoidance system (Shiba and Daimon 2003; Shimamura et al. 2003; Stevens et al. 2002). Secondary aerenchyma forms as a white spongy tissue filled with gas spaces on stem, hypocotyls, tap root, adventitious roots and root nodules of plants like soybean (*Glycine* spp.), purple loosestrife (*Lathyrus salicaria* L.), and sesbania (*Sesbania* spp.) (Saraswati et al. 1992; Shiba and Daimon 2003; Shimamura et al. 2003; Stevens et al. 2002).

Research has provided both direct and indirect evidence for the role of secondary aerenchyma in gas exchange and flood tolerance. Shimamura et al. (2003) reported a two fold increase in the porosity of flooded soybean hypocotyls having well developed secondary aerenchyma. Stevens et al. (1997) observed very low tissue density and high porosity of >60% in purple loosestrife stem bases having secondary aerenchyma.

Pasting of a barrier (Vaseline) on the hypocotyls above water level reduced gas exchange and consequently the growth of flooded soybean plants (Shimamura et al. 2003). Similar findings were reported by Stevens et al. (2002) in purple loosestrife. Thomas et al. (2005) discussed partial recovery of nitrogen metabolism in flooded soybean as an indirect measurement of increased oxygen availability due to secondary aerenchyma formation.

The overall objective of the current study was to evaluate the effect of flood depth on Texasweed growth and reproduction. The specific aim was to determine the flood depth needed for death of Texasweed in the absence of chemical weed control.

Materials and Methods

Research was conducted in 2007 and 2008 at the Louisiana State University Agricultural Center Northeast Research Station near St. Joseph, Louisiana using Sharkey clay soil (very fine, montmorillonitic, nonacid, Vertic Haplaquept) with pH 6.1 and 2.1% organic matter. Naturally dehisced seeds from mature Texasweed plants, cut and kept in shade at room temperature, were used in this research. The research was conducted under field conditions using 3 L capacity plastic pots. Pots were filled with a Sharkey clay soil taken from a fallow field and 15 Texasweed seeds were planted per pot. Plants were thinned to three plants per pot 3 days after emergence and to one plant per pot 10 days after emergence.

Two stages of Texasweed plants, two to three leaf stage and four to five leaf stage were obtained at the time of flood establishment. The two stages were obtained at the same time by delayed planting. Enough pots were prepared to provide the required number of plants of the two stages. Flooding conditions were created by placing potted plants in 1.3 m x 0.7 m x 0.7 m stock tanks[1]. Flood depths of 10, 15, 20 and 30 cm were achieved by siphoning off the excess depth of water in the troughs using drainage pipes of appropriate height (Figure 4.1). The potted plants were not provided with any supplemental nutrition. The study was a two-factor factorial experiment conducted in a completely randomized split-plot design with three replications. The four flood depths and a no-flood control were randomized to the water tanks (whole plot). The plants (pots) of the two Texasweed stages (sub-plot treatment) were then placed in each trough at the time of flood establishment.

Figure 4.1 (a) layout of the experiment; (b) and (c) detailed view of the water tanks; (d) potted Texasweed plants used in the study.

Destructive samples were taken at 7, 14, and 28 days after treatment (DAT). One plant from each experimental unit was removed to record plant height, leaf area per plant, and plant dry weight. Plant height was measured from the base of the plant to the tip of the third leaf from the top. Plants were separated into leaves and stem, and dried at 60°C to a constant weight.

Total leaf area per plant was measured using LICOR LI-3050A conveyer leaf area meter[2]. Total dry weight per plant was obtained as the sum of leaf and stem dry weight. Percent stem biomass was calculated by dividing stem dry weight by total dry weight. Data on number of fruits (capsules) per plant were also recorded at the time of last observation at 28 DAT.

The data were analyzed using MIXED procedure of SAS to study the effect of flood depth and Texasweed stage on Texasweed growth and number of fruits per plant (SAS 2003). Year was considered a random effect. Tukey's test was used for mean separation and Letter groupings were generated using the PDMIX800 macro in SAS (Saxton 1998). Linear and quadratic contrasts were constructed to study the trend of plant height against flood depth.

Leaf area per plant and total above ground dry matter data obtained at 28 DAT were used to model these growth characters as a function of flood depth. The data were converted to percent of no-flood control before model fitting. The average of the observations for no-flood control was used to convert the data to percent of control. NLMIXED procedure of SAS (SAS 2003) was used to fit various nonlinear models. Year was considered a random effect. Null-model likelihood ratio tests for nested models and Akaike's information criteria (AIC) values for unrelated models were used to compare different models and the criteria of better fit and parsimony was used to select a final model for each growth character.

Results and Discussion

For Texasweed height, an interaction between flood depth and Texasweed growth stage was observed. For both the two- to three-leaf and four- to five-leaf stages, the height differences between plants in different flood depths appeared as early as 7 days after flooding and the magnitude of these differences increased with time (Figure 4.2).

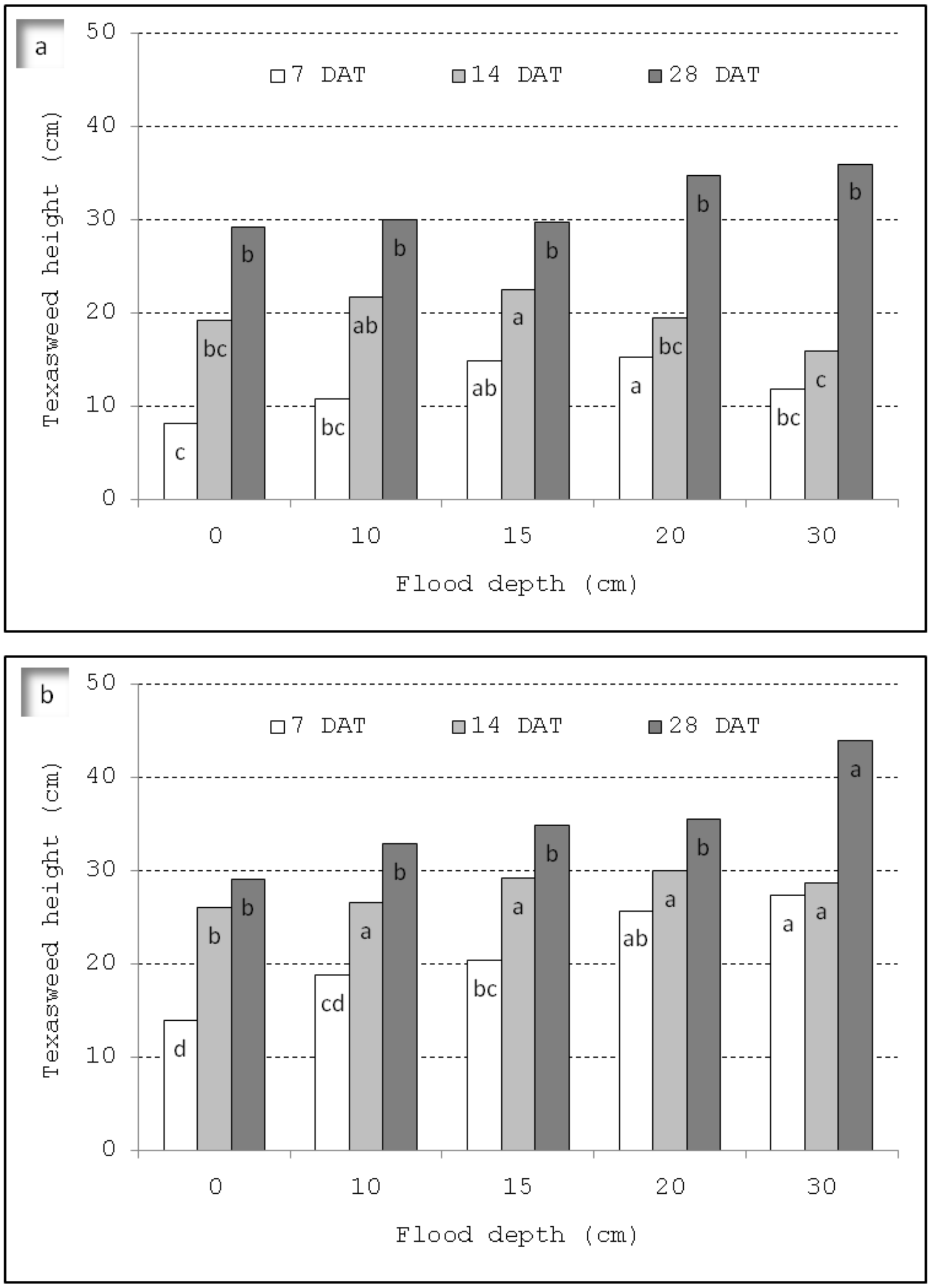

Figure 4.2 Effect of flood depth on Texasweed height: a) two to three-leaf stage, b) four to five-leaf stage. DAT=days after treatment. Means within each stage and DAT followed by a common letter are not different at P = 0.05 using Tukey's test; P-value for contrasts constructed to study change in height with increasing flood depth:
2-3 leaf stage, 7 DAT, linear = 0.0077, quadratic = 0.0013;
2-3 leaf stage, 14 DAT, linear = 0.0467, quadratic = 0.0025;
2-3 leaf stage, 28 DAT, linear = 0.0018, quadratic = 0.3608;
4-5 leaf stage, 7 DAT, linear = 0.0001, quadratic = 0.4398;
4-5 leaf stage, 14 DAT, linear = 0.0718, quadratic = 0.2901;
4-5 leaf stage, 28 DAT, linear = 0.0001, quadratic = 0.1195.

For two- to three-leaf stage, a quadratic trend of plant height against flood depth was observed at 7 and 14 DAT; however, the trend became liner at 28 DAT with the tallest plants in 30-cm flood depth. After 7 days of flood establishment, four- to five-leaf stage Texasweed plants in 10- and 15-cm flood depths emerged above the water level; however, in case of two to three leaf stage plants, only the plants in 10-cm flood depth were able to emerge above the water (Figure 4.2a). By 14 DAT, two- to three-leaf stage plants in 15-cm flood depths were also above the water; however, in case of four- to five-leaf Texasweed all but those in 30-cm flood depth were above the water. Here also, the plant height was 28.7 cm that was just below the water level (Figure 4.2 b).

A logistic model, $Y = Y_{max}/(1+(X/X_0)^b)$, was found to best fit the leaf area per plant and total above ground biomass data recorded at 28 DAT. Here, Y is the dependent variable and X is flood depth. Parameters Y_{max}, X0 and b represent the maximum asymptotic response, flood depth for achieving 50% of 'Y_{max}' and the instantaneous growth or decay rate at X_0, respectively.

For leaf area per plant, a model with different X_0 values for the two Texasweed stages had a better fit (Figure 4.3). For both two- to three-leaf and four- to five-leaf stages, the fitted model showed gradual decrease in leaf area per plant with an increase in flood depth. The flood depth required for 50% leaf area reduction was estimated to be 12.2 cm and 17.5 cm for two- to three-leaf stage and four- to five-leaf stage, respectively (Table 4.1).

For Texasweed above ground biomass, a model with different X_0 parameter values for the two stages had a better fit than the model with equal X_0 values (Figure 4.4). For both two- to three-leaf and four- to five-leaf stage, the above ground biomass decreased with an increase in flood depth. Table 4.1 shows that the flood depth required for 50% reduction in above ground biomass was characteristically higher for four- to five-leaf stage (28.8 cm) than two- to three-leaf stage (15 cm).

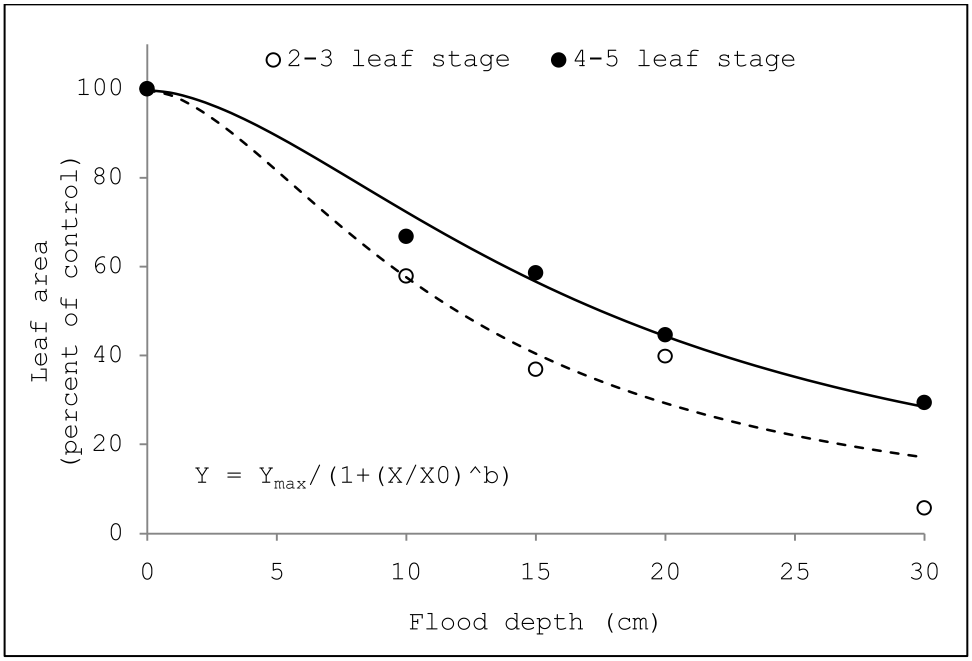

Figure 4.3. Effect of flood depth and Texasweed stage on Texasweed leaf area, 28 days after treatment. Actual leaf area in no-flood control was 227 and 261 cm^2/plant for 2-3 leaf stage and 4-5 leaf stage, respectively.

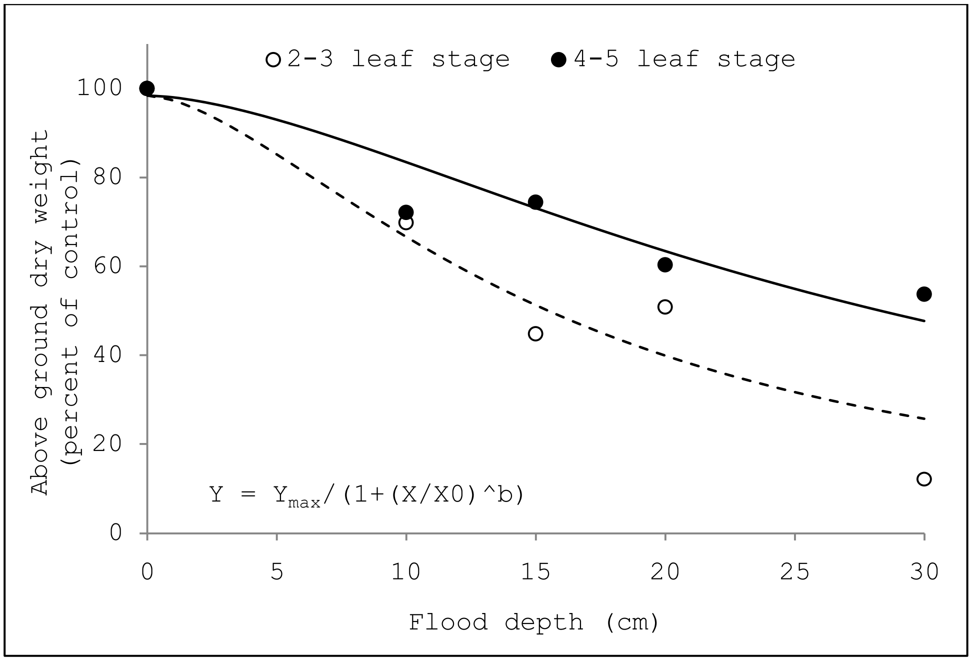

Figure 4.4. Effect of flood depth and Texasweed stage on Texasweed above ground dry weight, 28 days after treatment. Actual dry weight in no-flood control was 2.068 and 3.588 g/plant for 2-3 leaf stage and 4-5 leaf stage, respectively.

Table 4.1 Regression parameters (and standard errors) for effect of flood depth on Texasweed growth 28 days after treatment (DAT).

		Parameters for log-logistic equation					
Response variable	Texaswed stage	Upper limit (a)		GR_{50}[a] (X0)		Slope (b)	
Leaf area	2-3 leaf	99.63	(6.66)	12.20	(2.08)	1.72	(0.33)
	4-5 leaf	99.63	(6.66)	17.46	(2.21)	1.72	(0.33)
Above ground dry weight	2-3 leaf	98.40	(9.15)	15.82	(5.04)	1.62	(0.43)
	4-5 leaf	98.40	(9.15)	28.87	(5.63)	1.62	(0.43)

[a] GR_{50} refers to the flood depth (cm) at which the model predicts that the response is 50% of control.

Dry matter partitioning was affected by both Texasweed stage and flood depth (Table 4.2). At 7 and 14 DAT, the four to five leaf stage Texasweed plants had higher percent stem biomass than the two to three leaf stage plants (Table 4.2). No difference was observed at 28 DAT. Although, total biomass decreased under flooded conditions (Figure 4.4), biomass partitioning to the stem increased (Table 4.2). The response was not similar across the observation dates (DAT) and an interaction between flood depth and DAT for percent stem biomass was observed. At 7 DAT, Texasweed plants allocated 45 to 51% of their above ground biomass to stem (Table 4.2) but no effect of flood depths was observed. Differences appeared at 14 DAT when plants in 15-, 20-, and 30-cm flood depths had higher percent stem biomass than those in no flood. The differences among these three flood depths were, however, not significant at this time. At 28 DAT, plants in 30-cm flood depth further increased their biomass allocation to stem and stem constituted 74% of the total plant biomass. Increased biomass partitioning to stem seems to be the plant strategy to allow plant growth above the water level as soon as possible.

Table 4.2 Effect of flood depth and Texasweed stage at the time of flood establishment on percent stem biomass and Texasweed fruit production.[a]

Factor	Level	Percent stem biomass			Fruits/plant[b]
		7 DAT	14 DAT	28 DAT	28 DAT
Flood depth (cm)	0	45 a	49 c	45 c	5 (2.26) a
	10	49 a	59 b	54 bc	3 (1.57) b
	15	51 a	61 ab	59 b	2 (1.45) b
	20	46 a	61 ab	62 b	1 (1.03) bc
	30	48 a	66 a	74 a	1 (0.57) c
Texaswed stage	2-3 leaf	44 b	54 b	58 a	2 (1.14) b
	4-5 leaf	52 a	62 a	60 a	3 (1.61) a

[a] Means within each column followed by a common letter are not significantly different at P=0.05 using Tukey’s test.

[b] Values in parentheses are the $Y=\sqrt{(X+0.25)}$ transformed values.

Fruit production, at 28 DAT, by Texasweed plants was also affected by plant stage and flood depth (Table 4.2). Most of the plants were able to emerge above the water level and produce fruits (Figure 4.2). Averaged across the flood depths, the four to five leaf stage plants produced more fruits than the two to three leaf stage plants. Fruit production decreased with increasing flood depth (Table 4.2).

Adventitious roots and a spongy tissue were produced on the submerged parts of the Texasweed plants (Figure 4.5). Similar tissue production under flooded conditions has been reported in soybean (*Soybean max* L.), purple loosestrife, sesbania (*Sesbania* spp.) (Saraswati et al. 1992; Shiba and Daimon 2002; Shimamura et al. 2003; Stevens et al. 2002). The tissue was described as secondary aerenchyma and was called phellem (Shimamura et al. 2003). Research with other dicot plants has provided both direct and indirect evidence for the role of secondary aerenchyma in gas exchange and flood tolerance (Shimamura et al. 2003; Stevens et al. 2002; Thomas et al. 2005).

We suspect that the secondary aerenchyma formed on the submerged parts of Texasweed plants also plays a role in its flood tolerance. No attempt was, however, made to study this aspect.

The recommended flood depth in the rice paddies are 5- to 10-cm (Bollich et al. 1999). In the current study, a 10-cm flood provided only about 30 and 15% growth reduction in two to three leaf and four to five leaf stage Texasweed plants, respectively (Figure 4.4). Plants of both the stages emerged above the 10-cm water level within 7 days of flooding. The results of the current study, thus, suggest that flooding alone will not be a viable option for managing emerged Texasweed in drill-seeded rice. However, flooding has been reported to increase the effectiveness of chemical weed control in rice (Avila et al. 2005; Masson et al. 2001; Williams et al. 1990). Williams et al. (1990) reported that in the absence of chemical control at least 20-cm deep flood was required for satisfactory barnyardgrass control; with herbicide application weed control improved in all water depths and even a 5-cm flood provided 83% barnyardgrass control. Masson et al. (2001) also reported more than 80% barnyardgrass control under 5-, 10- and 20-cm flood depths when used in conjunction with imazethapyr at 140 g ai/ha applied preemergence or postemergence. Therefore, an integrated use of herbicides and flood management is a possibility for Texasweed management in rice and further research is required to study this aspect.

Figure 4.5 Phellem and adventitious roots on the submerged stem of a Texasweed plant.

End Notes

[1] Round End Poly Stock Tank (Granite Gray): Model No. 52112027S. Behlen Mfg. Co., 4025 E. 23rd St., PO Box 569, Columbus, Nebraska-68602, USA.

[2] LI-COR, Inc., 4421 Superior Street, P.O. Box 4425, Lincoln, Nebraska-68504, USA.

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Chapter 5

Bensulfuron-methyl Interaction with Penoxsulam and Bispyribac-sodium for Texasweed Control in Drill-Seeded Rice

Introduction

Weed management programs generally involve a complex integration of various cultural, mechanical, biological, chemical, and other methods of weed control. However, owing to its high benefit to cost ratio and tremendous increase in labor productivity, chemical weed control has evolved into a standard weed management approach in crop production systems around the globe (Bastiaans et al. 2008; Hill 1982; McWhorter 1984). A number of preemergence (PRE) and postemergence (POST) herbicides are also available in rice (Anonymous 2010) and US rice producers rely primarily on herbicides for weed control; 95% of the rice planted in the United States in 2006 received some type of herbicide treatment (USDA 2006).

Mixing of two or more herbicides is extensively practiced in modern crop production systems to reduce the cost of application and broaden the spectrum of weed control. Newly labeled herbicides are, therefore, evaluated in mixtures with other herbicides recommended for the crop. These field level trials are aimed at integrating new herbicides into already established weed management programs. Mixing of herbicides is generally based on the assumption that herbicides in a mixture behave and act independently (Damalas 2004). However, the interaction between component herbicides in a mixture can alter their chemical properties and can increase or decrease their activity compared to the component herbicides applied individually (Damalas 2004). An increase or decrease in weed control due to herbicide mixture implies synergism or antagonism, respectively; the effect is called additive if the mixture results in a weed control level equal to the sum of that obtained with each herbicide applied alone (Colby 1967; Green 1989; Hatzios and Penner 1985). An optimum herbicide combination or mixture would be one that provides either additive or preferably synergistic effect on target weeds without any toxicity to the crop.

The type and the magnitude of interaction between component herbicides in a mixture primarily depends on the herbicide properties including chemical family, absorption, translocation, mechanism of action, pathway of metabolism as well as the weed or crop species involved (Damalas 2004). In an extensive summary of studies on herbicide-herbicide interactions, Zhang et al. (1995) observed that regardless of the plant species or herbicides involved, antagonism occurs three times more often than synergism. Damalas (2004) concluded that in general, antagonism occurs more frequently in grassy weeds than broadleaf weeds and also in mixtures where the component herbicides belong to different chemical families. Conversely synergism occurs more frequently in broadleaf weed species and in mixtures where the component herbicides belong to the same chemical family. Based on the concentration addition (CA) model Cedergreen et al. (2007) did not find any antagonistic interaction between herbicides with the same molecular site of action. However, herbicides with different site of action showed antagonism in 70% of the mixtures.

Acetolactate synthase (ALS) (EC 4.1.3.18) inhibiting herbicides generally show antagonism with the herbicides having other modes of action; the interaction with other ALS inhibiting herbicides is mostly additive or synergistic (Cedergreen et al. 2007; Green 1989; Nelson et al. 1998; Schuster et al. 2008; Zhang et al. 2005). Cedergreen et al. (2007) reported additive interaction between metsulfuron-methyl [2-[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]-oxomethyl]sulfamoyl]benzoic acid methyl ester] and triasulfuron [1-[2-(2-chloroethoxy)phenyl]sulfonyl-3-(4-methoxy-6-methyl-1,3,5-triazin-2-yl)urea]. Simpson and Stoller (1995 and 1996) reported synergistic interaction between thifensulfuron [3-[[[[(4-methoxy-6-methyl-

1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid] at 4.4 g ai/ha and imazethapyr [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid] at 70 g ai/ha on sulfonylurea tolerant soybean (STS). Simpson and Stoller (1995) also reported higher control of smooth pigweed (*Amaranthus hybridus* L.), common lambsquarters (*Chenopodium album* L.), velvetleaf (*Abutilon theophrasti* Medik.), common cocklebur (*Xanthium strumarium* L.), tall morningglory [*Ipomoea purpurea* (L.) Roth], and ivyleaf morningglory (*Ipomoea hederacia* Jacq.) with thifensulfuron at 4.4 g/ha plus imazethapyr at 70 g/ha as compared to these herbicides applied alone. Reducing the rate of one or both herbicides did not decrease smooth pigweed and common cocklebur control. Nelson et al. (1998) also reported greater common lambsquarter control with thifensulfuron at 2.2 g/ha plus imazethapyr at 70 g/ha compared to these herbicides applied alone. Damalas et al. (2008) reported higher efficacy of bispyribac-sodium plus azimsulfuron [N-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]-1-methyl-4-(2-methyl-2H-tetrazol-5-yl)-1H-pyrazole-5-sulfonamide] on early watergrass [*Echinochloa oryzoides* (Ard.) Fritsch] and late watergrass [*Echinochloa phyllopogon* (Stapf) Koso-Pol.] as compared to bispyribac-sodium applied alone. The increased weed control was, however, dependent on bispyribac-sodium rate and weed stage at the time of herbicide application. Godara et al. (2007) reported higher broadleaf weed control in rice with mixtures of penoxsulam or bispyribac-sodium with bensulfuron-methyl compared with these herbicides applied alone; suggesting interaction between the component herbicides in the mixtures.

The objective of this research was to study bensulfuron-methyl interaction with penoxsulam and bispyribac-sodium for control of lagre, five- to six-leaf, Texasweed in drill-seeded rice. The specific aim was to determine optimum bensulfuron-methyl rate in mixture with penoxsulam or bispyribac-sodium.

Materials and Methods

Field experiments were conducted in 2006, 2007, and 2008 at the Louisiana State University Agricultural Center Northeast Research Station near St. Joseph, Louisiana on Sharkey clay soil (very fine, montmorillonitic, nonacid, Vertic Haplaquept) with a pH of 6.1 and 2.1% organic matter. Field preparation in each year consisted of a fall disking followed by a spring disking and two passes in opposite directions with a two-way bed conditioner equipped with rolling baskets and S-tine harrows set to operate 6 cm deep. 'Cocodrie' rice was drill-seeded at 100 kg/ha on April 24, May 9, and May 1 during 2006, 2007, and 2008, respectively, to plots measuring 2 by 4.5 m.

A randomized complete block (RCB) design with two-factor factorial arrangement of treatments and three replications was used in both studies. Factor A for the penoxsulam and bensulfuron-methyl interaction study was penoxsulam[1] applied at 0, 35, 40.3 g ai/ha, and for bispyribac-sodium and bensulfuron-methyl interaction study bispyribac-sodium[2] applied at 0, 14.6, and 29.2 g ai/ha. Factor B for both the studies was bensulfuron-methyl[3] applied at 0, 11, 22, and 33 g ai/ha. Crop oil concentrate[4] at 2% v/v was used the study involving penoxsulam and a non-ionic spray adjuvent[5] at 1.0% v/v was used in the study involving bispyribac-sodium. All the treatments in both studies were applied LPOST when Texasweed [*Caperonia palustris* (L.) St. Hil.] was 10 to 12 cm tall with five to six leaves. Application timings were on May 23, June 11, and June 2 in 2006, 2007, and 2008, respectively.

The study area was surface irrigated immediately after the application of PRE herbicides and as needed until permanent floods were established. Permanent floods were established 5 to 6 weeks after planting when rice reached four to five leaf stage. Nitrogen in the form of prilled Urea (46-0-

0) was applied at 126 kg/ha just before permanent flood. An additional 42 kg/ha of nitrogen was applied at the panicle initiation stage of rice. Grasses were managed by a PRE application of clomazone[6] at 560 g ai/ha and POST application of fenoxaprop-ethyl[7] at 122 g ai/ha. Clomazone and fenoxaprop-ethyl provide excellent grass control but at the rates used have limited to no activity on Texasweed (Anonymous 2010). Herbicide treatments were applied using a CO_2 pressurized backpack sprayer calibrated to deliver 140 L/ha at 276 kPa.

Visual ratings for Texasweed control were recorded on a 0 to 100% scale where 0 = no control or injury and 100 = plant death. Rice injury, in the form of stunting and chlorosis, was visually estimated at 7 DAT using a 0 to 100 scale where 0 = no injury and 100 = plant death.

To study the effect of various treatments on Texasweed control, the data were analysed using MIXED procedure of SAS (SAS 2003). Year, replication (nested within year) and all interactions involving either of these effects were considered random effects. Type III statistics were used to test significance of fixed effects. Least square means were used and mean separation was carried out using Tukey's test at an overall P = 0.05. Letter groupings were generated using the PDMIX800 macro in SAS (Saxton 1998).

Additionally, NLMIXED procedure of SAS (SAS 2003) as described by Blouin et al. (2004) was used for the analysis of interaction effect of herbicides. Expected percent weed control for various herbicide tank mixtures were calculated using the formula: Exp = X + Y − (XY/100), where 'Exp' is the expected weed control, and X and Y are the observed percent weed control by herbicide A and B alone,respectively (Colby 1967). Expected and observed percent weed control of each herbicide mixture was then compared using NLMIXED *T* tests generated using the methodology described by Blouin et al. (2004). An increase or decrease in observed percent control as compared to expected percent control was declared synergism or antagonism, respectively; the response was classified as additive when there was no difference between observed and expected percent weed control. Linear and quadratic contrasts as described by Blouin et al. (2004) were also constructed to study change in herbicide interaction over time and p-values thus obtained were compared to 0.05 level to test the statistical significance of the change. Negative or positive values for linear effects indicated an increase or decrease, respectively, in synergism over time. Negative or positive values for quadratic effects indicated a convex or concave change, respectively, in synergism over time.

Results and Discussion

Penoxsulam and Bensulfuron-methyl Combinations. The results in Table 5.1 show that the maximum Texasweed control with bensulfuron-methyl was 58%, and was obtained with 33 g/ha rate at 14 DAT. Similarly, the maximum Texasweed control with penoxsulam was 63%, and was obtained with 40.3 g/ha rate at 42 DAT. At both 28 DAT and 42 DAT, Texasweed control with penoxsulam at 35 g/ha (27%) was 27%. Mixting bensulfuron-methyl with penoxsulam at 35 g/ha or 40.3 g/ha increased Texasweed control. There was no difference in Texasweed control between the two penoxsulam rates in the presence of bensulfuron-methyl at 22 g/ha or higer rate. Bensulfuron-methyl at all rates when mixed with penoxsulam at 40.3 g/ha provided similar Texasweed control.

Although, the data in Table 5.1 show that neither penoxsulam nor bensulfuron-methyl alone at any rate provided satisfactory Texasweed control, A significant interactions between penoxsulam and bensulfuron-methyl for Texasweed control was observed at all the three observation dates (Table 5.2). As indicated by the significant increase in the observed control compared to the expected control (Table 5.2), the interaction was synergistic for most of the combinations. The combinations involving highest rates of either or both herbicides resulted in additive effect at 14 DAT. The magnitude of synergistic effect was greater for the mixtures involving lower doses of the two herbicides than for those involving higher doses. As measured by the mostly negative value of the linear contrasts (Table 5.2). The synergistic effect of the combinations either increased or remained constant over time. Penoxsulam at 35 or 40.3 g/ha plus bensulfuron-methyl at 33 g/ha combinations showed a quadratic trend for change in synergism with time.

Bispyribac-sodium and Bensulfuron-methyl Combinations. In terms of percent control, bensulfuron-methyl at 33 g/ha and bispyribac-sodium at 14.6 g/ha applied alone provided 60 to 67% and 50 to 59% Texasweed control, respectively (Table 5.3). At 28 and 42 DAT, bispyribac-sodium at 29.2 g/ha provided greater Texasweed control than at 14.6 g/ha rate. Bensulfuron-methyl when mixed with bispyribac-sodium, increased Texasweed control. There was no difference between bensulfuron-methyl rates in the presence of bispyribac-sodium. Bispyribac-sodium at 14.6 or 29.2 g/ha plus bensulfuron-methyl at 11 g/ha provided more than 85% Texasweed control.

Table 5.1 Texasweed control with penoxsulam and bensulfuron-methyl alone and in combination at 14, 28, and 42 days after treatment (DAT), averaged over 2007 and 2008.[a]

penoxsulam (g ai/ha)	bensulfuron-methyl (g ai/ha)	Texasweed control (%)		
		14 DAT	28 DAT	42 DAT
0	0	0 e	0 f	0 d
	11	15 de	0 f	0 d
	22	30 cd	0 f	0 d
	33	58 b	48 de	32 c
35	0	50 bc	27 e	27 c
	11	75 ab	67 bcd	77 ab
	22	83 a	84 ab	81 ab
	33	80 a	92 a	88 a
40.3	0	60 b	62 cd	63 b
	11	75 ab	78 abc	79 ab
	22	82 a	88 ab	83 ab
	33	84 a	83 abc	87 a

[a] Abbreviations: DAT, days after treatment

[b] Means within each column followed by a common letter are not significantly different based on Tukey's test at P=0.05.

Table 5.2 Changes in activity of penoxsulam and bensulfuron-methyl combinations on Texasweed over time, averaged over 2007 and 2008.[a]

		penoxsulam			
		35 g ai/ha		40.3 g ai/ha	
bensulfuron-methyl (g ai/ha)	DAT	OBS-EXP[c]	P-value[b]	OBS-EXP	P-value
11	14	17	0.0039	8	0.1576
	28	40	<0.0001	16	0.0088
	42	49	<0.0001	15	0.0124
	L	-32	<0.0001	-7	0.2447
	Q	-7	0.2765	-5	0.4208
22	14	18	0.0011	10	0.0641
	28	56	<0.0001	26	<0.0001
	42	53	<0.0001	20	0.0016
	L	-35	<0.0001	-10	0.1195
	Q	-21	0.0008	-12	0.0398
33	14	2	0.7366	0	0.9195
	28	29	<0.0001	3	0.5255
	42	38	<0.0001	12	0.0290
	L	-36	<0.0001	-11	0.0453
	Q	-10	0.0643	3	0.5345

[a] Abbreviations: DAT, days after treatment; OBS, observed; EXP, expected; L, linear contrast of the difference between the observed and the expected values within an herbicide combination; Q, linear contrast of the difference between the observed and the expected values within an herbicide combination.

[b] P values are used to compare the differences between the observed and the expected value or to indicate the significance of linear and quadratic contrasts.

[c] The observed values were obtained by visual observation while the expected values were calculated on the basis of Colby’s formula. A negative or positive value indicates an antagonistic or synergistic response, respectively. Negative or positive values for linear contrast indicate an increase or decrease, respectively, in synergism over time. Negative or positive values for quadratic contrast indicate a convex or concave change, respectively, in synergism over time.

Table 5.3 Texasweed control with bispyribac-sodium and bensulfuron-methyl alone and in combination at 14, 28, and 42 days after treatment (DAT), averaged over 2007 and 2008.[a]

bispyribac-sodium (g ai/ha)	bensulfuron-methyl (g ai/ha)	Texasweed control (%)		
		14 DAT	28 DAT	42 DAT
0	0	7 d	7 e	18 d
	11	13 d	19 d	23 d
	22	30 cd	26 d	26 d
	33	66 ab	67 c	60 c
14.6	0	50 bc	59 c	50 c
	11	74 ab	95 a	85 ab
	22	84 a	99 a	98 a
	33	81 a	93 a	94 a
29.2	0	79 ab	79 b	78 b
	11	78 ab	89 ab	88 ab
	22	84 a	99 a	98 a
	33	84 a	99 a	98 a

[a] Abbreviations: DAT, days after treatment.

[b] Means within each column followed by the same letter are not significantly different based on Tukey’s test at P=0.05.

The interaction between bispyribac-sodium and bensulfuron-methyl for Texasweed control was either additive or synergistic (Table 5.4). The combinations involving higher doses of either one or both herbicides: bispyribac-sodium at 29.2 g/ha and bensulfuron-methyl at 33 g/ha resulted in additive effect; whereas, the combinations involving reduced rates of both the herbicides resulted in synergistic effect. The non-significant linear and quadratic contrasts indicated no effect of rating time on the magnitude of interaction.

Similar Texasweed control with bensulfuron-methyl mixture with reduced or full rates of either penoxsulam or bispyribac-sodium also suggested the possibility of reducing penoxsulam and bispyribac-sodium use rates without adversely affecting Texasweed control. Reduction in the penoxsulam or bispyribac-sodium rates; however, may not be desirable because of its possible adverse effect on grassy weed control. The effect of tank mixing bensulfuron-methyl with penoxsulam or bispyribac-sodium on grass weed control was not recorded. It can be concluded that for Texasweed control, bensulfuron-methyl particularly at lower rates interacts synergistically with both penoxsulam and bispyribac-sodium. Bensulfuron-methyl can be mixed with either penoxsulam or bispyribac-sodium for increasing their activity on Texasweed; however, a minimum of 11 g/ha rate of bensulfuron-methyl will be required to provide a satisfactory control.

Table 5.4 Changes in activity of bispyribac-sodium and bensulfuron-methyl combinations on Texasweed over time, averaged over 2007 and 2008.[a]

		bispyribac-sodium			
		14.6 g ai/ha		29.2 g ai/ha	
bensulfuron-methyl (g ai/ha)	DAT	OBS-EXP[c]	P-value[b]	OBS-EXP	P-value
11	14	16	0.0440	-5	0.5303
	28	28	0.0017	5	0.5674
	42	22	0.0148	4	0.0427
	L	-6	0.5664	-8	0.3973
	Q	-9	0.3119	-5	0.5565
22	14	17	0.0212	-2	0.7418
	28	28	0.0018	12	0.1452
	42	32	0.0005	12	0.1399
	L	-15	0.1486	-14	0.1370
	Q	-3	0.7352	-7	0.4184
33	14	-2	0.7691	-8	0.1934
	28	0	0.9568	-1	0.9033
	42	7	0.3309	0	0.9607
	L	-9	0.3036	-9	0.3086
	Q	3	0.6853	-3	0.6700

[a] Abbreviations: DAT, days after treatment; OBS, observed; EXP, expected; L, linear contrast of the difference between the observed and the expected values within an herbicide combination; Q, linear contrast of the difference between the observed and the expected values within an herbicide combination.

[b] P values are used to compare the differences between the observed and the expected value or to indicate the significance of linear and quadratic contrasts.

[c] The observed values were obtained by visual observation while the expected values were calculated on the basis of Colby’s formula. A negative or positive value indicates an antagonistic or synergistic response, respectively. Negative or positive values for linear contrast indicate an increase or decrease, respectively, in synergism over time. Negative or positive values for quadratic contrast indicate a convex or concave change, respectively, in synergism over time.

End Notes

[1] Grasp® herbicide label. Dow AgroScience, Indianapolis, IN 46268, USA.

[2] Regiment™ herbicide label. Valent Corporation, Walnut Creek, CA 94596, USA.

[3] Londax™ herbicide label. United Phosphorus, Inc., 630 freedom Business Center, Suite 402 King of Prussia, PA 19406, USA.

[4] Agri-dex®, Helena Chemical Co., 225 Schilling Boulevard, Suite 300, Collierville, TN 38017, USA.

[5] Dyne-A-Pak, Helena Chemical Co., 225 Schilling Boulevard, Suite 300, Collierville, TN 38017, USA.

[6] Command® 3 ME herbicide label. FMC Corporation, Agricultural Products Group, 1735 Market Street, Philadelphia, PA 19103, USA.

[7] Ricestar HT® herbicide label. Bayer CropScience, P.O. Box 12014, 2 T.W. Alexander Dr., Research Triangle Park, NC 27709, USA.

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Chapter 6

Evaluation of V-10142 for Texasweed Control in Drill-Seeded Rice

Introduction

In direct-seeded rice, weeds emerge with the crop; therefore, early season weed management is very important. A number of preemergence (PRE) herbicides are available for use in rice (Anonymous 2010a). Clomazone [2-[(2-chlorophenyl) methyl]-4,4-dimethyl-3-isoxazolidinone] and quinclorac [3,7-dichloroquinoline -8-carboxylic acid] are the two major PRE herbicides used in conventional (non-clearfield) rice production in the USA (Anonymous 2010a; USDA 2006). Thiobencarb [S-((4-chlorophenyl) methyl)diethylcarbamothioate] and pendimethalin [3,4-Dimethyl-2,6-dinitro-N-pentan-3-yl-aniline] are also used, but to a lesser extent (USDA 2006).

Clomazone belongs to the isoxazolidinone family and provides excellent control of *Echinochloa* spp. (Mitchell and Hatfield 1996; Webster et al. 1999; Zhang et al. 2005). In 2006, 50% of the US rice acreage received clomazone application (USDA 2006). Although, clomazone provides control of grasses and has very good residual activity in rice (Mitchell and Gage 1999; Mitchell and Hatfield 1996; Webster et al. 1999), it does not control several key broadleaf and sedge species when applied at recommended rates (Brommer et al. 2000; Williams et al. 2004).

Quinclorac controls of barnyadgrass (Street and Muller 1993; Baltazar and Smith 1994), hemp sesbania, pitted morningglory (*Ipomoea lacunose* L.), jointvetch (*Aeschynomene* spp. L.)(Street and Mueller 1993; Grossmann 1998). However, quinclorac has little to no activity on sprangletop (*Leptochloa* spp. L.)(Jordan 1997; Anonymous 2010a) and the development of quinclorac-resistant barnyardgrass (Lopez-Martinez 1997; Lovelace et al. 2007; Malik et al. 2010) has limited its use in rice.

Pendimethalin and thiobencarb are applied as delayed preemergence (DPRE), which is an application made after rice has imbibed water for germination but before emergence (Anonymous 2010a). Pendimethalin controls grasses and small-seeded broadleaf weeds (Byrd and York 1987) but is not effective against sedges and large seeded broadleaf weeds like spreading dayflower and Texasweed (Anonymous 2010a). Thiobencarb provides good control of barnyardgrass, sprangletop, and annual sedges but has limited activity on broadleaf weeds; the period of residual control is also less than three weeks (Anonymous 2010a).

In general, the available PRE herbicides in rice are very effective against grasses which are the dominant and most troublesome weeds in rice (Holm et al. 1977; Fischer et al. 2004; Valverde et al. 2001). The high degree of residual grass control provided by these herbicides allows the farmers to delay their POST applications up to four to five weeks after planting (Bill Williams[1], personal communication). Many broadleaf weeds like Texasweed [*Caperonia palustris* (L.) St. Hil.] grow big and become difficult to control by that time (Godara et al. 2007). Kurtz (2004) also reported reduced activity of postemergence herbicides on three to four leaf Texasweed in soybean (*Glycine max* L.) crop and emphasized the need for its control at an early stage.

Although, the early season weed control achieved by PRE herbicides lays the ground work for a healthy crop, postemergence weed management is often required to maximize the crop quality and yield (Ampong-Nyarko and DeDatta 1991). Ever since the development of 2,4-D in 1940s efforts have constantly been made to provide better options of broad-spectrum and effective chemical weed control in rice. Propanil [N-(3,4-Dichlorophenyl) propanamide] first registered in the USA in 1972 (Anonymous 2010b) controls both grass and broadleaf weeds (Crawford and Jordan 1995; Jordan et al. 1997). However, long-term repeated use of propanil has led to the development of propanil-resistance in barnyardgrass (Baltazar and Smith 1994; Carey et al. 1995; Talbert 2007). Despite the development of propanil resistance in barnyrdgrass, it is still the most widely used postemergence herbicide in rice (USDA 2006). Other herbicides like quinclorac, triclopyr [[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid], carfentrazone-ethyl [ethyl α,2-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]-4-fluorobenzenepropanoate], acifluorfen [5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid] also provide postemergence broadleaf weed control in rice (Anonymous 2010a; Jordan 1997; Mitchell and Sims 1998; Rosser et al. 1988). However, the most recent entries in the list of herbicides registered for use in rice are the acetolactate synthase (ALS) (EC 4.1.3.18) inhibiting herbicides.

ALS herbicides used in rice primarily include sulfonylureas and imidazolinones (Anonymous 2010a). Imazethapyr [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid] is an imidazolinone herbicide registered for use in imidazolinone resistant (IR) rice (Anonymous 2008a). Imazethapyr provides effective control of red rice, barnyardgrass, and broadleaf signalgrass in rice (Klingaman et al. 1992; Masson and Webster 2001; Masson et al. 2001). It is, however, weak on several broadleaf weeds such as hemp sesbania, northern jointvetch, and Indian jointvetch (Klingaman et al. 1992; Masson and Webster 2001; Zhang et al. 2001). Mixture of imazethapyr with other herbicides like bispyribac-sodium, carfentrazone, or propanil improves overall weed control, especially hemp sesbania (Zhang et al. 2006).

Bensulfuron-methyl [methyl 2-[[[[[(4,6-dimethoxy-2-pyrimidinyl) amino]carbonyl]amino]sulfonyl]methyl]benzoate] and halosulfuron-methyl [methyl 3-chloro-5-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl] amino]sulfonyl]-1-methyl-1H-pyrazole-4-carboxylate] are the two most popular sulfonylurea herbicides in rice and were used on about 15% of the U.S. rice acreage in 2006 (USDA 2006). Bensulfuron-methyl controls broadleaf weeds such as eclipta, hemp sesbania, purple ammania, and can suppress barnyardgrass growth (Jordan 1995). Halosulfuron is effective against sedges and supresses broadleaf weeds (Mudge et al. 2005; Murphy and Lindquist 2002; Zhang et al. 2006).

Penoxsulam [2-(2,2-difluoroethoxy)-6-(trifluoromethyl-N-(5,8-dimethoxy[1,2,4] triazolo[1,5-c]pyrimidin-2-yl))benzenesulfonamide], belongs to the trizolopyrimidine sulfonamide family and was developed by Dow Agrosciences LLC[2]. It provides PRE and POST control of certain grassy and broadleaf weeds (Johnson et al. 2009). Lassiter et al. (2006) reported that penoxsulam at 20 to 40 g ai/ha applied postemergence in dry-seeded rice provided good to excellent control of annual and perennial *Echinochloa* species, hemp sesbania, northern jointvetch [*Aeschynomene virginica* (L.) Britton, Sterns & Poggenb.], spreading dayflower, ducksalad [*Heteranthera limosa* (Sw.) Willd.], alligatorweed, Texas/Mexicanweed, smartweed (*Polygonum* spp.), annual sedges (*Cyperus* spp.), and several other broadleaf weeds. They also reported 2 to 4 weeks residual weed control with penoxsulam in dry-seeded rice. Strahan (2004) reported 83 and 85% Texasweed control 70 days after treatment (DAT) with penoxsulam at 40.3 and 50.5 g/ha, respectively. Williams et al. (2004) reported only 40% hemp sesbania control two weeks after flooding with a preemergence application of penoxsulam at 30 g/ha plus clomazone at 560 g ai/ha in drill-seeded rice. The control of barnyardgrass, Amazon sprangletop [*Leptochloa panicoides* (J. Presl) Hitchc.], and rice flatsedge (*Cyperus iria* L.) in the same treatment was 90, 70, and 86%, respectively. Penoxsulam showed greater broadleaf weeds activity when applied postemergence than preemergence.

Bispyribac-sodium [Sodium 2,6-bis[(4,6-dimethoxypyrimidin-2-yl)oxy]benzoate], belongs to the pyrimidinyl thiobenzoates family and was developed by Valent Co. USA[3] for postemergence control of certain grassy and broadleaf in rice (Anonymous 2008b). Bispyribac-sodium provides broad-spectrum weed control in rice but has no residual activity (Esqueda and Rosales 2004). Single applications of 20 and 22 g/ha bispyribac-sodium to four to six leaf rice provided good control of barnyardgrass, hemp sesbania, and northern jointvetch. However, the control of broadleaf signalgrass, palmleaf morningglory (*Ipomoea wrightii* A. Gray), and bearded sprangletop [*Leptochloa fusca* (L.) Kunth ssp. fascicularis (Lam.) N. Snow] was inadequate (Schmidt et al. 1999). Williams (1999) also reported 98 to 100% barnyardgrass and hemp sesbania control from mid- to late-postemergence applications of bispyribac-sodium at 20 or 23 g/ha.

V-10142 (imazosulfuron) [2-chloro-N-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]imidazo[1,2-a]pyridine-3-sulfonamide], an ALS inhibitor, is being developed by Valent Co. USA[3] for weed control in drill- and water-seeded rice. It primarily controls broadleaf weeds and sedges but can suppresses annual grasses (Baron 2006). Boydston and Felix (2008) reported 91 to 98% yellow nutsedge (*Cyperus esculentus* L.) control with V-10142. Henry and Sladek (2008) reported 90 to 100% yellow nutsedge and up to 90% purple nutsedge (*Cyperus rotundus* L.) control in bermudagrass [*Cynodon dactylon* (L.) Pers.] with two postemergence applications of V-10142 at 560 g/ha. Imazosulfuron may prove to be an effective preemergence herbicide for broadleaf weed and sedge control in drill-seeded rice. The herbicide if compatible in tank mixture with bispyribac-sodium or penoxsulam also has a potential of providing excellent broad-spectrum postemergence weed control in drill-seeded rice.

The objective of this research was to evaluate V-10142 programs involving rate, application timings and combinations with other herbicides for PRE and POST Texasweed control in drill-seeded rice.

Materials and Methods

Field experiments were conducted in 2006, 2007, and 2008 at the Louisiana State University Agricultural Center Northeast Research Station near St. Joseph, Louisiana on Sharkey clay (very fine, montmorillonitic, nonacid, Vertic Haplaquept) with pH 6.1 and 2.1% organic matter. Field preparation during each year consisted of a fall disking followed by a spring disking and two passes in opposite directions with a two-way bed conditioner equipped with rolling baskets and S-tine harrows set to operate 6 cm deep. 'Cocodrie' rice was drill-seeded on April 24, May 9, and April 29 in 2006, 2007, and 2008 respectively, at 100 kg/ha to plots measuring 2 by 4.5 m.

The study area was surface irrigated immediately after the application of preemergence herbicides and as needed until permanent floods were established. Permanent floods were established 5 to 6 weeks after planting when rice reached four- to five-leaf stage. Nitrogen in the form of prilled Urea (46-0-0) was applied at 126 kg/ha just before permanent flood. At panicle initiation an additional 42 kg/ha of nitrogen was applied. Herbicide treatments were applied using a CO_2 pressurized backpack sprayer calibrated to deliver 140 L/ha at 276 kPa.

For the preemergence study, a randomized complete block design with three replications was used in all the three years. The treatments consisted of different V-10142[4] rates: 56, 112, 168, 224, 336, 450, 504, and 560 g ai/ha. Clomazone[5] at 560 g/ha applied PRE and fenoxaprop-ethyl[6] at 111 g ai/ha applied POST were used to control barnyardgrass in the experimental plots. In 2007 and 2008, additional treatments of V-10142 rates (112, 168, and 224 g/ha) without clomazone were also included in the experiments to test any possible interaction between clomazone and V-10142.

For the postemergence study, a randomized complete block (RCB) design with three replications was used in all the years. The treatments consisted of various combinations of herbicides, their rates and three application times (Table 6.1). The herbicides used were V-10142[4], bispyribac-sodium[7], penoxsulam[8], halosulfuron-methyl[9], and bensulfuron-methyl[10]. Crop oil concentrate[11] at 1% or 1.75% v/v was used in the treatments involving V-10142 alone and penoxsulam, respectively. A non-ionic spray adjuvent[12] at 1.5% v/v was used in the treatments involving bispyribac-sodium. The three herbicide application times: EPOST (two- to three-leaf stage Texasweed), LPOST (four- to five-leaf stage Texasweed), and 3 DPF (3 days prior to flood) were on May 9, May 27 and June 6, in 2006 and May 28, June 9 and June 11 in 2007, respectively. Fenoxaprop-ethyl[6] at 111 g ai/ha was also applied 3 DPF to all experimental plots for grass control (Table 6.1).

In all experiments, visual Texasweed control ratings were recorded on a 0 to 100% scale where 0 = no control or injury and 100 = plant death. Rice injury, in the form of stunting and chlorosis, was visually estimated 7 days after treatment (DAT) using a 0 to 100% scale where 0 = no injury and 100 = plant death. Rough rice yield was obtained using a small-plot combine. Data were analysed using MIXED procedure of SAS (SAS 2003). Year, replication (nested within year) and all interactions involving either of these effects were considered random effects. Observation dates (DAT/DAP) were used as repeated measures to compare the weed control response over time. Type III statistics were used to test significance of fixed effects. Least square means were used and mean separation was carried out using Tukey’s test at an overall P=0.05. Additionally for preemergecne study, the effect of clomazone on V-10142 was determined by contrasts analysis. ESTIMATE statements were used to construct the contrasts for comparing treatments containing V-10142 with clomozone at 560 g ai/ha (clomozone+) and without clomazone (clomozone-). Letter groupings were generated using the PDMIX800 macro in SAS (Saxton 1998).

Table 6.1 Postemergence treatments involving herbicides, their combinations, rates, and application time.

Treatment[a]	Rate (g ai/ha)	Application time[b]
Nontreated	--	--
V-10142	224	EPOST
bispyribac	17.6	EPOST
bispyribac + V-10142	17.6 + 112	EPOST
bispyribac + V-10142	17.6 + 168	EPOST
bispyribac + V-10142	17.6 + 224	EPOST
V-10142	224.0	LPOST
bispyribac	17.6	LPOST
bispyribac + V-10142	17.6 + 122	LPOST
bispyribac + V-10142	17.6 + 168	LPOST
bispyribac + V-10142	17.6 + 224	LPOST
bispyribac	29.2	3 DPF
penoxsulam	40.3	3 DPF
bispyribac + V-10142	29.2 + 224	3 DPF
penoxsulam + V-10142	40.3 + 224	3 DPF
bispyribac + halosulfuron	29.2 + 27.4	3 DPF
penoxsulam + bensulfuron	40.3 + 22.0	3 DPF

[a] Clomazone at 560 g ai/ha as preemergence and fenoxaprop-ethyl at 111 g ai/ha as postemergence were applied in all the treatments for grass control; crop oil concentrate (COC)[7] at 1% and 1.75% v/v was used in treatments involving V-10142 alone and penoxsulam, respectively; NIS[12] at 1.5% v/v was used in treatments involving bispyribac-sodium.

[b] EPOST=2-3 leaf Texasweed; LPOST=4-5 leaf Texasweed; 3 DPF=3 days prior to flood.

Results and Discussion

Preemergence Study. V-10142 demonstrated preemergence activity on Texasweed (Table 6.2). At 2 WAP, all V-10142 rates provided more than 90% Texasweed control and no difference was observed among the rates. Texasweed control with V-10142 at 56 g/ha decreased with time (Table 6.2). The results pointed towards reduced residual control <112 g/ha V-10142 rates. Texasweed control with V-10142 at 168 g/ha and higher rates remained more or less constant over the entire duration of the experiment. At 12 WAP, V-10142 at 168 g/ha provided 95% control, which was at par with all other higher rates.

Table 6.2 Effect of various preemergence herbicide treatments on Texasweed control and rough rice yield.

Treatment[a] (PRE)	Rate (g/ha)	Texasweed control (%)[b]				Rough rice yield (%)[c]
		2 WAP	4 WAP	8 WAP	12 WAP	
Nontreated	-	0 h	0 h	0 h	0 h	100 c
V-10142 + clomazone	56 560	91 abcd	59 f	30 g	0 h	119 bc
V-10142 + clomazone	112 560	92 abcd	80 e	88 abcde	79 e	181 a
V-10142 + clomazone	168 560	94 abcd	84 cde	93 abcd	95 abcd	178 a
V-10142 + clomazone	224 560	93 abcd	86 bcde	93 abcd	88 abcde	179 a
V-10142 + clomazone	336 560	95 a	90 abcd	93 abcd	94 abc	176 a
V-10142 + clomazone	450 560	95 a	93 abcd	93 abcd	88 abcde	176 a
V-10142 + clomazone	504 560	96 ab	89 abcde	93 abcd	92 abcd	175 a
V-10142 + clomazone	560 560	95 ab	93 abc	93 abcd	95 ab	185 a
V-10142	112	96 ab	83 cde	93 abcd	83 abcde	114 bc
V-10142	168	91 abcd	83 de	93 abcd	95 abcd	117 bc
V-10142	224	92 abcd	85 abcde	93 abcd	95 abcd	143 b

[a] Fenoxaprop-ethyl at 111 g ai/ha was applied as postemergence in all the treatments for grass control.
[b] Means followed by a common letter are not significantly different at P=0.05 using Tukey's test
[c] Percent of untreated; actual rough rice yield in nontreated was 3077 kg/ha.

The effect of clomazone on V-10142 activity was only evident at 12 WAP (Table 6.3). As indicated by the negative values of the estimates, Texasweed control was lower in clomazone+ treatments as compared to clomazone- treatments. The observed results could either be due to interaction between the two herbicides or increased Texasweed growth in the clomazone+ treatments as a result of reduced barnyardgrass competition. A greater barnyardgrass control in clomazone+ treatments as compared with clomazone- treatments is evident from the significant positive values of the contrast estimates for barnyardgrass control (Table 6.3).

Table 6.3 Estimates and P-values for the contrasts constructed for comparing clomazone+ and clomazone- preemergence V-10142 treatments.

Variable	Estimate	P-value[b]
Texasweed control 2 WAP	0	0.9399
Texasweed control 4 WAP	-4	0.4545
Texasweed control 8 WAP	-5	0.0546
Texasweed control 12 WAP	-10	0.0356
barnyadgrass control 2 WAP	35	<0.0001
barnyadgrass control 4 WAP	38	0.0279
Rough rice yield	5045	<0.0001

[a] Estimates of the difference between clomazone+ and clomazone- treatments; +ve values indicate greater effect of clomazone+ treatments and vice-versa.
[b] P-value for difference of estimated value from zero.

No rice injury was observed in any of the treatments at 7 DAT (data not shown). Rough rice yield was affected by herbicide treatments (Table 6.2). Clomazone at 560 g/ha plus V-10142 at 56 g/ha did not increase rice yield over weedy check, which may be due to poor Texasweed control in this treatment. Other rates resulted in a 75 to 85% yield increase over the weedy check. The yield differences among the V-10142 rates above 56 g/ha were insignificant. The linear contrast of colomazone+ and colomazone- treatments (Table 6.3) showed clomazone effect on rough rice yield. The average yield of colomazone+ treatments was 5045 kg/ha more than the clomazone- treatments (Table 6.3). Although, grass weeds in the experimental area were selectively controlled with postemergence application of fenoxaprop-ethyl at 111 g/ha, the control was not 100%. The better grassy weed control in clomazone+ treatments compared to clomazone- treatments (Table 6.3) appears to be responsible for the observed yield differences between the two set of treatments.

Postemergence Study. Bispyribac-sodium at 17.6 g/ha applied EPOST provided 76% Texasweed control 4 WAP (Table 6.4). Percent control by bispyribac-sodium decreased with time; it provided 52% and 0% Texasweed control at 8 and 12 WAP, respectively. V-10142 on the other hand provided more than 90% Texasweed control on the same observation dates. The greater efficacy of V-10142, applied EPOST, compared to bispyribac-sodium may be due to good residual activity of V-10142 as observed in preemergence study above. Compared to bispyribac-sodium applied alone, bispyribac-sodium plus V-10142, applied EPOST, increased Texasweed control (Table 6.4). Even the mixture involving lower V-10142 rate (112 g/ha) provided more than 90% Texasweed control. However, V-10142 alone at 224 g/ha was as effective as its combinations with bispyribac-sodium.

LPOST application of bispyribac-sodium at 17.6 g ai/ha provided 32% Texasweed control (Table 6.4). Moreover, as the application timing changed from EPOST to LPOST, the Texasweed control at 12 WAP with 224 g/ha V-10142 dropped from 90% to 15% (Table 6.4). The results suggest that V-10142 is more effective against two- to three-leaf Texasweed than four- to five-leaf Texasweed. Similar conclusions were drawn by Kurtz (2004) for Texasweed control with other herbicides in soybean crop. LPOST application of bispyribac-sodium plus V-10142 improved Texasweed control compared with these herbicides alone (Table 6.4). Texasweed control further increased as V-10142 rate increased in the mixtures. At 12 WAP, bispyribac-sodium at 17.6 g/ha plus V-10142 at 112 g/ha applied LPOST provided 62% Texasweed control; whereas, the control with V-10142 at 224 g/ha in the mixture was 84%. Among 3 DPF applications, both bispyribac-sodium at 29.2 g/ha and penoxsulam at 40.3 g/ha controlled Texasweed less than 54% at all observation dates (Table 6.4). Texasweed control from mixture of V-10142 at 224 g/ha with bispyribac-sodium or penoxsulam was, however, more than 90%. The level of control obtained by these mixtures was similar to that obtained by bispyribac-sodium plus

Table 6.4 Texasweed control and rice grain yield in different postemergence treatments.

Treatment[a] (POST)	Rate (g/ha)	Application time[b]	Texasweed control			Rough rice yield (kg/ha)[c]
			4 WAP	8 WAP	12 WAP	
			-------------------% [c]	---------------		
Nontreated	--	--	0 h	0 h	0 h	--
V-10142	224	EPOST	84 ab	93 a	90 ab	2715 h
bispyribac	17.6	EPOST	77 abcd	52 ef	0 h	3801 gh
bispyribac + V-10142	17.6 + 112	EPOST	88 ab	93 a	92 ab	5375 def
bispyribac + V-10142	17.6 + 168	EPOST	88 ab	93 a	93 ab	6217 bcd
bispyribac + V-10142	17.6 + 224	EPOST	88 ab	89 ab	87 ab	6000 bcde
V-10142	224	LPOST	-	60 de	15 h	2769 h
bispyribac	17.6	LPOST	-	52 ef	32 g	5619 cde
bispyribac + V-10142	17.6 + 122	LPOST	-	78 abc	62 cde	5212 def
bispyribac + V-10142	17.6 + 168	LPOST	-	93 ab	77 bc	4886 efg
bispyribac + V-10142	17.6 + 224	LPOST	-	88 ab	84 ab	5511 cde
bispyribac	29.2	3 DPF	-	54 e	32 g	6108 bcd
penoxsulam	40.3	3 DPF	-	37 fg	32 g	4208 fg
bispyribac + V-10142	29.2 + 224	3 DPF	-	90 ab	92 ab	8660 a
penoxsulam + V-10142	40.3 + 224	3 DPF	-	94 ab	91 ab	7326 ab
bispyribac + halosulfuron	29.2 + 27.4	3 DPF	-	90 ab	93 a	6597 bc
penoxsulam + bensulfuron	40.3 + 22.0	3 DPF	-	91 ab	93 ab	6585 bc

[a] Clomazone at 560 g ai/ha as preemergence and fenoxaprop-ethyl at 111 g ai/ha as postemergence were applied in all the treatments for grass control; crop oil concentrate (COC)[7] at 1% and 1.75% v/v was used in treatments involving V-10142 alone and penoxsulam, respectively; NIS[12] at 1.5% v/v was used in treatments involving bispyribac-sodium.

[b] EPOST=2-3 leaf Texasweed; LPOST=4-5 leaf Texasweed; 3 DPF=3 days prior to flood.

[c] Means followed by a common letter are not significantly different at P=0.05 using Tukey’s test.

halosulfuron-methyl or penoxsulam plus bensulfuron-methyl, which are very popular among the Louisiana rice growers for postemergence weed management in rice (Bill Williams[1], personal communication).

Among 3 DPF applications, both bispyribac-sodium at 29.2 g/ha and penoxsulam at 40.3 g/ha controlled Texasweed less than 54% at all observation dates (Table 6.4). Texasweed control from mixture of V-10142 at 224 g/ha with bispyribac-sodium or penoxsulam was, however, more than 90%. The level of control obtained by these mixtures was similar to that obtained by bispyribac-sodium plus halosulfuron-methyl or penoxsulam plus bensulfuron-methyl, which are very popular among the Louisiana rice growers for postemergence weed management in rice (Bill Williams[1], personal communication).

Herbicide treatments applied 3 DPF provided higher grain yields compared to other timings (Table 6.4). Within the three application timings, herbicide combinations generally provided higher grain yields than the herbicides applied alone. EPOST applications of V-10142 at 224 g/ha provided the lowest rice yield (2715 kg/ha), which was not different than the 3801 kg/ha obtained with bispyribac-sodium at 17.6 g/ha. However, LPOST application of 17.6 g/ha bispyribac-sodium provided almost twice the grain yield obtained with LPOST application of V-10142 at 224 g/ha. This difference could not be explained in terms of Texasweed control as the performance of both the treatments was similar and unsatisfactory in terms of Texasweed control (Table 6.4).

Barnyardgrass was the dominant grass present in high densities in the experimental area. Barnyardgrass pressure was lowered with the postemergence application of fenoxaprop-ethyl at 111 g/ha. However, the fact that bispyribac-sodium has barnyardgrass activity (DeWitt et al. 1999; Schmidt 1999; Williams 1999) may have caused differences in barnyardgrass infestation between LPOST applications of V-10142 and bispyribac-sodium alone thus affecting rice yields. Barnyardgrass control data was, however, not collected.

Visual rice injury was not observed in any of the treatments (data not shown). The lack of yield reduction in V-10142 tank mixtures compared to bensulfuron-methyl and bensulfuron-methyl tank mixtures (Table 6.4) also suggests no adverse effect of V-10142 on rice growth and yield.

The results show that V-10142 has PRE activity against Texasweed. Weed control increased with increasing V-10142 rates, but 168 g ai/ha rate provided more than 90% control, which was statistically at par with all other higher rates. V-10142 alone at 224 g/ha applied EPOST provided above 90% Texasweed control and was as effective as its combination with bispyribac-sodium. V-10142, therefore, can be applied by itself at EPOST to manage Texasweed in rice. None of the herbicides applied alone at LPOST or 3 DPF timings provided satisfactory Texasweed control. V-10142 applied LPOST or 3 DPF may not be useful by itself, but can be mixed at 224 g/ha with bispyribac-sodium at 29.2 g/ha or penoxsulam at 40.3 g/ha to improve Texasweed control in rice.

End Notes

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[2] Dow AgroScience, Indianapolis, IN 46268, USA.

[3] Valent Corporation, Walnut Creek, CA 94596, USA.

[4] V-10142, experimental compound. Valent Corporation, Walnut Creek, CA 94596, USA.

[5] Command® 3 ME herbicide label. FMC Corporation, Agricultural Products Group, 1735 Market Street, Philadelphia, PA 19103, USA.

[6] Ricestar HT® herbicide label. Bayer CropScience, P.O. Box 12014, 2 T.W. Alexander Dr., Research Triangle Park, NC 27709, USA.

[7] Regiment™ herbicide label. Valent Corporation, Walnut Creek, CA 94596, USA.

[8] Grasp™ 2 SC herbicide label. Dow AgroScience, Indianapolis, IN 46268, USA.

[9] Permit™ herbicide label. Gowan Company LLC. 370 Main Street, Yuma, AZ 85364, USA.

[10] Londax™ herbicide label. United Phosphorus, Inc., 630 Freedom Business Center, Suite 402 King of Prussia, PA 19406, USA.

[11] Agri-dex®, Helena Chemical Co., 225 Schilling Boulevard, Suite 300, Collierville, TN 38017, USA.

[12] Dyne-A-Pak, Helena Chemical Co., 225 Schilling Boulevard, Suite 300, Collierville, TN 38017, USA.

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Chapter 7

Summary

Texasweed [*Caperonia palustris* (L.) St. Hil.] is an annual broadleaved plant belonging to the Euphorbiaceae family (USDA 2007). Texasweed has been identified as a growing problem in rice and other crops in southern USA (Bennett 2003; Gianessi et al. 2002; Koger et al. 2004; Poston et al. 2007). The present research was conducted to study Texasweed interference and its management in drill-seeded rice. Results from this research can be used to design an integrated Texasweed management program in rice.

Season long Texaswed interference at 1 plant/m^2 was estimated to cause 5.1% yield loss in drill-seeded rice. Yield loss due to 50 plants/m^2 was approximately 61%. Even 10 plants/m^2 reduced rice yield by 24-31%. The critical period of Texasweed interference was estimated to be between 0 and 6 weeks after rice emergence. Although, the critical period of interference varied between the two years of study, it underlines the importance of early season Texasweed management. The differences between the two years may be due to the differences in Texasweed density.

Both the Texasweed density and area of influence studies demonstrated that the rice yield reduction due to Texasweed interference was associated with a reduction in the number of rice culms/m^2 and grains per panicle. The 1000-grain weight of rice was not affected by Texasweed interference. Path analysis indicated yield component compensation i.e. a reduction in the number of culms/m^2 caused an increase in number of grains per panicle. However, this effect was not strong enough to reverse the detrimental effect of reduced culms/m^2 on rice yield. These results differ from the work by Smith (1968 and 1984) that demonstrated that broadleaf weeds reduce rice yield by affecting grain filling process and that broadleaf weeds are not competitive if removed before they begin to shade rice. However, present research demonstrates that in the case of Texasweed interference, rice yield is reduced much earlier. Both the Texasweed density and area of influence studies show that Texasweed interference reduces rice yield by affecting number of culms per unit area. Culms per unit area are a function of tillering, which begins when rice is at four- to five-leaf stage. The results indicate that substantial yield losses can occur if Texasweed control is delayed beyond 2 WAE. In addition, rice should be kept free of Texasweed until 5 to 6 WAE or permanent flood establishment.

Shade had no effect on Texasweed emergence, but significantly reduced its growth. At 100 days after study initiation, 50, 70, and 90% shade caused 31, 47, and 90% reduction in above ground dry matter production per plant, respectively. Texasweed height was affected by shade. Texasweed in 30 and 50% shade at 14 DAI, were smaller than those in full sun. Quadratic contrasts at 28 DAI and onwards also indicated that Texasweed height, at a given DAI, increased with increasing shade level up to 70% and then decreased. After 28 DAI, 70% shade resulted in taller plants; the height was increased 15 to 21% compared with 0% shade. Even 90% shade was not able to cause more than 16% reduction in Texasweed height. Although fruit production was significantly reduced due to shade, Texasweed was still able to set fruit in 90% shade.

Texasweed seemed to mitigate the adverse effect of shade on growth by increasing its specific leaf area (SLA) and percent leaf biomass. The results of our study are similar to those observed in other plant species (Patterson 1979; Gibson et al. 2001). Increasing SLA and percent leaf biomass, thus, appears to be a strategy for efficient allocation of fresh biomass for light capture and carbohydrate synthesis, which can be used for height increase until the plant rises above the crop canopy. Thus, Texasweed plants growing under shade, depending upon the crop height, may emerge above the crop canopy and offset any growth reduction caused by shade earlier. Patterson (1979) and

Gibson et al. (2001) in their research with *Ammannia* spp. also concluded that weed control through light manipulation alone is unlikely in a rice crop.

Growth differences between plants transferred directly and gradually to a given shade level suggest that weed growth under a real crop canopy, where shade increases gradually, will be different than under constant shade. Thus, studies where plants are gradually exposed to increasing shade levels are better at modeling weed growth under a crop canopy.

Texasweed plants were able to survive and produce fruits in all flood depths; however, growth and fruit production were significantly reduced due to flooding. A 30-cm flood depth caused 76% and 41% dry matter reduction reduction in two- to three-leaf and four- to five-leaf stage Texasweed, respectively. Increasing flood depths resulted in greater allocation of biomass to the stem. As a result of stem elongation, Texasweed plants under all flood depths were able to form a canopy above the water level. Texasweed plants produced adventitious roots and a thick spongy tissue (secondary aerenchyma) in the submerged plant parts, which possibly plays a role in Texasweed’s survival under flooded conditions. The recommended flood depth for rice in Louisiana is 5- to 10-cm (Bollich et al. 1999). A 10-cm flood in our research caused only about 30 and 15% biomass reduction in two- to three-leaf and four- to five-leaf stage Texasweed, respectively. Plants of both the stages emerged above the 10-cm flood within seven days of flooding. These results, thus, suggest that flooding alone may not be a viable option for Texasweed management in drill-seeded rice but can possibly be manipulated to enhance the effectiveness of postemergence herbicides, which is an aspect that needs further investigation.

Bensulfuron-methyl interacted synergistically with both penoxsulam and bispyribac-sodium. None of the herbicides applied alone provided satisfactory control of five- to six-leaf Texasweed; however, mixture of bensulfuron-methyl with penoxsulam at 35.0 or 40.3 g ai/ha or bispyribac-sodium at 14.6 or 29.2 g ai/ha improved control of large Texasweed. However, a minimum of 11 g/ha rate of bensulfuron-methyl will be required to provide a satisfactory control.

Similar Texasweed control with bensulfuron-methyl mixture with reduced or full rates of either penoxsulam or bispyribac-sodium also suggested the possibility of reducing penoxsulam and bispyribac-sodium use rates without adversely affecting Texasweed control. Reduction in the penoxsulam or bispyribac-sodium rates; however, may not be desirable because of its possible adverse effect on grass weed control.

V-10142 showed PRE activity against Texasweed. Texasweed control increased with increasing V-10142 rates, but 168 g ai/ha rate provided more than 90% Texasweed control, which was equal to that obtained with higher V-10142 rates. V-10142 at 224 g/ha applied EPOST provided above 90% Texasweed control and was as effective as when applied with bispyribac-sodium. None of the herbicides applied alone at LPOST or 3 DPF timings was effective on Texasweed. V-10142 may not be useful by itself at LPOST and 3 DPF applications, but can be mixed at 224 g/ha with bispyribac-sodium at 29.2 g/ha or penoxsulam at 40.3 g/ha to provide satisfactory Texasweed control in rice.

Results demonstrate that Texasweed in drill-seeded rice should be controlled within two weeks of rice emergence to avoid significant yield losses. Early permanent flood establishment and cultural practices that promote early shade development can help reduce Texasweed growth but will not provide a complete control. Penoxsulam at 40.3 g/ha or bispyribac-sodium at 29.2 g/ha plus bensulfuron at 11 g/ha can be used to manage four- to five-leaf Texasweed in rice. However, owing to residual activity, V-10142 appears to be the most promising herbicide for Texasweed control. Once available for use in rice, V-10142 can be used in PRE and POST weed management programs in drill-seeded rice for Texasweed control.

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Vita

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