2016

Prickly Sida (Sida spinosa L.): Biology and In-Crop and Post-Harvest Management Programs

Josh Thomas Copes
Louisiana State University and Agricultural and Mechanical College, jcopes@agcenter.lsu.edu

PRICKLY SIDA (*SIDA SPINOSA* L.): BIOLOGY AND IN-CROP AND POST-HARVEST MANAGEMENT PROGRAMS

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
Josh T. Copes
B.S., University of Louisiana at Monroe, 2007
M.S., Louisiana State University, 2010
May 2016

ACKNOWLEDGMENTS

Foremost I would like to thank my Lord and Savior Jesus Christ for all the blessings and guidance he has bestowed upon me. His word has given me strength and confidence to face any task set before me.

I would like to thank my family and friends for always being a source of strength and encouragement and recreation. To my mother for her endless prayers, advice and counseling that have helped shape me into the person I am today. To my father who always made sure I had the resources necessary to make it. For my Granny who always took care of me, prayed for me, and who is an example of strength and love that I hope to be for my family. I wish my Grandma was still here. I miss her greatly. She was a strong woman who was devoted to her family and who taught me so many wonderful things growing up that I will pass on to my children and grandchildren. To my wife Caitlin who has been beside me throughout my Ph.D. program. I am truly blessed to have such a beautiful, wonderful and loving wife who is always there for me no matter what. You make me want to be the best I can be. I look forward to our journey through life together. I love you. To Dr. Bill Williams, my former major advisor, for all of the advice and teachings you provided.

A special thanks to Dr. Rakesh Godara. You were instrumental in providing advice and wisdom in the design and execution of my experiments. Thank you for your patience and willingness to help with anything. You are dear friend and colleague who I can always count on and look forward to working with in the future.

Thank you Dr. Jim Griffin for being gracious and stepping in as my major advisor upon Dr. Bill's departure. I will always be grateful for the countless hours you spent working, training and teaching me all the skills necessary for becoming a successful scientist. You are an excellent mentor, teacher, and scientist who I will strive to be like in my career. I hope that one day someone will look up to me as I do you. Thank you for all that you have done.

To my graduate committee, Dr. Jim Griffin, Dr. Donnie Miller, Dr. Eric Webster, Dr. Daniel Stephenson IV, and Dr. Rodrigo Valverde, thank you for your guidance and wisdom during my time in weed science. I appreciate the support and knowledge that you graciously bestowed upon me. I am truly blessed to have such a wonderful committee. I am indebted to each of you.

A special thanks to Dr. Donnie Miller for having confidence in me to become his research associate, and by providing me with the environment to learn and perform research which allowed for my personal growth and development. Everything you have done for me is greatly appreciated. You are a great example of a scientist and administrator.

To Dr. Daniel Stephenson IV who has always taken the time to answer my phone calls and visit with me and has provided me with precise answers and explanations, friendly advice and philosophy. Thank you for being a great mentor.

To Dr. Eric Webster for his willingness to coach our weed science team. Thank you for your time and teachings. It was a wonderful learning experience.

To Mr. Al Coco for always being a source of guidance and assistance and ensured my research was put in and cared for. Your advice and wisdom made my life and research efforts much easier. Thank you for being a great mentor and friend.

To the farm crew at the Northeast Research Station, Mr. Mike Goings, Mr. Ralph Bass, Mr. Stanley May, and Mr. Warren Ratcliff and also Dr. Rick Mascagni for being great friends and providing assistance whenever I was in need. A special thanks to Marcie Mathews who was always willing to help with my projects so I could accomplish the tasks at hand. The cookouts were a great fellowship time and I look forward to future ones. To the numerous student and

transient workers that tirelessly provided labor toward accomplishing my research objectives. Your work and time was greatly appreciated and I could not have done it without you.

As I reflect over the past several years I realize how truly blessed I am to have been mentored and educated by some of the best weed scientist. How blessed I am to have had the pleasure to work alongside such a conscientious and hardworking group of men at the Northeast Research Station, and the example they provided me of how a team works together. I would not trade a lifetime for the experiences and friends that I have made along this journey. I cannot express how grateful I am to each and every one of you. May God bless each of you. Thank you all for making this possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Prickly sida (*Sida spinosa* L.) is widely distributed in the southern U.S. and is a troublesome weed in many agronomic crops. In northeastern Louisiana on silty clay loam and clay soils, prickly sida seedling emergence began in early March when soil temperature reached 13.8 C and ceased in mid-October. Seasonal peaks in emergence were associated with rainfall events and variability in prickly sida emergence was observed between soil types and years. Total emergence was as high as 3,000 prickly sida plants m^{-2}. In shade studies, prickly sida was able to emerge and persist under a heavy shade environment and to produce a significant amount of seed when exposed to both increasing and decreasing shade levels as the growing season progressed. Under a season-long 30% shade environment, around 3,000 prickly sida seed were produced per plant. With exposure to 90% shade in the early season followed by a gradual decrease in shade to full sun, total seed production was around 8,100 seed per plant. In a weed control programs study, late season prickly sida control was 93% when glyphosate was applied both at-planting in late April/early May and postemergence (POST) in mid-May/late June. Soybean yield was increased an average of 10% when the residual herbicides chlorimuron-ethyl and tribenuron-methyl were applied with glyphosate plus 2,4-D preplant in mid-March compared with glyphosate plus 2,4-D alone. Yield was equivalent when glyphosate or glyphosate plus the residual herbicides flumioxazin, chlorimuron-ethyl, and thifensulfuron-methyl were applied at-planting and averaged approximately 25% greater than when no herbicide was applied at-planting. Application of 2,4-D or glyphosate plus 2,4-D to prickly sida reduced total seed production 78% compared with glyphosate alone. Herbicide treatments most effective for control of prickly sida present after crop harvest included diuron and linuron applied with glufosinate, paraquat, or glyphosate (75 to 85% control); diuron, atrazine, or 2,4-D ester applied with paraquat (74 to 77%); and 2,4-D ester and dicamba applied with glyphosate (75%).

CHAPTER 1
INTRODUCTION

Prickly sida (*Sida spinosa* L.) is a widely distributed and troublesome broadleaf weed in cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), peanut (*Arachis hypogaea* L.) and soybean [*Glycine max* (L.) Merr.] in the southern U.S (Webster and Coble 1997; Webster and Nichols 2012). Prickly sida was reported as the most troublesome weed of cotton in 1974 and second most troublesome in 1983 (Webster and Coble 1997). By 2008 and 2009 prickly sida ranked as the 19th most troublesome weed in corn and soybean and 14th in cotton (Webster and Nichols 2012). A Mississippi survey of weeds conducted by Rankins et al. (2005) found prickly sida present in 40% of soybean fields sampled, making it the most prevalent weed. Prickly sida was present in 45% of soybean fields in the Delta region, compared to 43% of fields in eastern Mississippi. Glyphosate, the foundation of most weed control programs, is most effective on prickly sida when applied at one to three leaf compared four or more leaves (Jordan et al. 1997). Variability in control of prickly sida with glyphosate was reduced when glyphosate was applied with of ammonium sulfate. In recent years in Louisiana, growers and consultants have reported increased problems with control of prickly sida in soybean.

PRICKLY SIDA (SIDA SPINOSA) BIOLOGY

Prickly sida belongs to the Malvacea family and is widely distributed in the sub-tropical and tropical regions of both hemispheres (Woodson et al. 1965). Prickly sida is an annual weed and has a slender, sparingly branched, and erect stem that can reach a height of 1.2 m (Bryson and DeFelice 2009). Leaves are polymorphic, mostly with a lanceolate or linear-oblong shape, crenate-serrate at the margins, and 2 to 6 cm long and 0.3 to 1.8 cm wide. Flowers are axillary, solitary, often with a very short accessory flowering branchlet in the same axil, and is attached by a slender pedicle 2 to 9 mm long. The calyx contains 5 sepals, 5 to 5.5 mm long; there are 5 yellow petals strongly oblique and 6 to 7 mm long. The fruit is composed of 5 trigonous mericarps 2.5 mm long with two short (0.5 to 0.8 mm) aristae at the apex. Seedling cotyledons are heart-shaped and slightly indented at the apex.

Eighteen to twenty one days of prickly sida seed development are required to be considered fully mature where seed contain less than 21 % moisture, are dormant, and do not imbibe water or germinate when incubated for 28 d (Egley 1976). Seeds that have acquired 12 to 16 d of development contain greater than 20% moisture and exhibit 80% germination after 4 week of incubation. Dehydration and seed coat-hardening occurs during the later stages of seed development, greater than 12 to 16 d-old seed. Storage at 35 C for 12 week or longer, resulted in greater than 90% germination (Baskin and Baskin 1984; Egley 1976). Puncturing the seed coat over the radicle or cotyledon allowed for water imbibition of all hard-seed, but the puncture over the radicle promoted greater than 90% germination (Egley 1976). Prickly sida has been observed to germinate in the field from April through September in north central Kentucky; suggesting that water permeability of seeds increases throughout the year (Baskin and Baskin 1984).

Prickly sida is also capable of germination under limited soil moisture. After 96 hour of incubation, prickly sida germination and radicle length was unaffected by osmotic pressures of 0, -300, and -600 kPa (Hoveland and Buchanan 1973). Even though some prickly sida seed germinated at an osmotic pressure of -1000 kPa, a significant reduction in radicle length was observed. Smith et al. (1992) reported significant reduction in prickly sida germination when osmotic stress of -200 kPa was imposed for 2 week, and seed germination was inhibited when osmotic stress exceeded -600 kPa. Soil pH range of 5.0 to 8.0 did not affect prickly sida germination. Prickly sida emergence of 80% was noted when seeds were planted at a 0.5 cm depth, while only 60, 50, 40, and 20% emergence was observed at depths of 1 to 1.5, 2.0 to 2.5, 3.0, 5.0 cm, respectively. Prickly sida did not emerge from depths greater than 5.0 cm.

Optimum temperatures for prickly sida germination occur from 30 to 40 C (Baskin and Baskin 1984; Smith et al. 1992) and light was not a requirement for germination in this temperature range. However, when scarified prickly sida seeds were maintained at day/night temperature regimes of 15/6 and 20/10 C, germination was greater in the dark than in the light (Baskin and Baskin 1984). Germination was not promoted by freezing and thawing or by incubation of seed at 5 C. Germination was enhanced by increasing temperature regimes and by subjecting seeds to wet/dry cycles; increasing temperature proved most effective in promoting germination. Both the number of permeable seeds and rate of germination increased with increasing temperatures. Seeds exposed to higher temperatures following a lower temperature regime germinated at greater percentages than those maintained continuously at the higher temperatures. Also, increasing the length of time the seeds remained at the lower temperature before transfer to higher temperatures increased germination. The lower temperature regime seemed to “precondition” the seed for a rapid increase in water permeability. Egley (1990) reported that in moist soil, viability of prickly sida seed exposed 1 d to 50 C was reduced to 45% and seed did not survive 12 hour at 60 C. Egley and Chandler (1983) reported that prickly sida viability was 21, 4, and less than 1%, after burial for 3.5, 4.5, and 5.5 years, respectively. Depth of burial did not influence prickly sida viability after 30 months, however, viable seed was only found at 8 cm (15%) and 38 cm (1%) (Egley and Chandler 1978).

POST-HARVEST WEED CONTROL

At harvest time, weed seeds can be classified based on the dispersal status and location: (1) shed a previous year and remaining in the soil seedbank; (2) not shed from the mother plant;

(3) shed the current year and remain on the soil surface; (4) shed the current year and gathered by the harvest operation (Davis 2008). Weed seed pools are dominated by a few grass and broadleaf weed species (Davis 2008; Kegode et al. 1999). Davis (2008) observed that in at least one crop (corn or soybean) during one of the two study years, the dominant weed species had a ratio ≥ 1 of undispersed seeds to seeds in the soil seedbank, indicating the potential for 1 year of seed rain to replenish or augment the soil seedbank. The current year's crop, corn or soybean, affected the risk for seedbank replenishment for certain weed species. Seedbank augmentation or replenishment is a common occurrence in commercial grain production systems managed with standard herbicide programs. Seed capture or destruction at harvest time may be practical, but it would require modifying harvesting equipment, whereas, management practices that target reducing seed production may be most effective. The development of effective management strategies that reduce weed fecundity, will be aided by species-level information that identify tactics most appropriate for a given weed spectrum.

Research has demonstrated that herbicides applied at early flower or pod set can reduce potential seedbank replenishment (Bennet and Shaw 2000; Biniak and Aldrich 1986; Brewer and Oliver 2007; Clay and Griffin 2000; Fawcett and Slife 1978; Hartzler and Battles 2001; Isaacs et al. 1989; Jha and Norsworthy 2012; Maun and Cavers 1969; Taylor and Oliver 1997; Thomas et al. 2005; Walker and Oliver 2008). Additionally, seed weight reduction, seed viability, and seedling recruitment can affect presence of plant species the following season (Jha and Norsworthy 2012). Herbicides can be used before soybean harvest to negatively affect weed seed number, seed weight, germination, and seedling growth parameters (Bennett and Shaw 2000). Glyphosate at 1.1 or 2.2 kg ai ha^{-1} applied alone or in combination with sodium chlorate (3.4 or

6.7 kg ai ha^{-1}) were effective in reducing weed seed production, seed weight, and seedling growth.

Applications of glyphosate made to weeds prior to reproductive development has been shown to reduce weed seed production (Brewer and Oliver 2007; Thomas et al. 2005). In a greenhouse experiment, when averaged over application timings (4-leaf, 8-leaf, 4-leaf followed by 8-leaf, and 12-leaf), glyphosate applied at 280 g ai ha^{-1} reduced sicklepod pod [*Senna obtusifolia* (L.) H.S. Irwin & Barneby] and seed numbers and total seed weight 79, 80, and 81%, respectively, (Thomas et al. 2005). Brewer and Oliver (2007) found that regardless of glyphosate rate (0.42, 0.84, 1.68 kg ae ha^{-1}) or application timing [3, 6, and 9 weeks after emergence (WAE)] spurred anoda [*Anoda cristata* (L.) Schlecht.] and hemp sesbania [*Sesbania herbacea* (P. Mill.) McVaugh] seed production was reduced at least 93%. It should be noted that by 9 WAE spurred anoda and hemp sesbania had begun reproductive development (flowering). For entireleaf morningglory [*Ipomoea hederacea* (L.) Jacq.], seed production was reduced 37% to 100% when glyphosate was applied at 3 or 6 WAE (prior to flowering). Seed production was reduced more when higher rates of glyphosate were used and when applications were made 3 WAE compared to 6 WAE. Hemp sesbania seed production was reduced 93 to 100% regardless of glyphosate application timing (3, 6, or 9 WAE) or rate (0.42, 0.84, or 1.68 kg ae ha^{-1}). When averaged over application timings of 8 to 10, 12 to 17, and 20 to 30 cm, glyphosate at 840 g ha^{-1} reduced velvetleaf (*Abutilon theophrasti* Medik.) biomass and capsule number/plant at least 90% (Hartzler and Battles 2001). All application timings were effective in reducing capsule number per plant, however, the later application timings tended to be more effective. In general glyphosate at 840 g ha^{-1} reduced dry weight and capsule number greater than glyphosate at 420 g ha^{-1}. Results have shown that in general, higher glyphosate rates were more effective than lower rates when application was made to weeds prior to reproductive development.

Glyphosate when applied to weeds at bud formation and early flower/heading has been shown to effectively reduce seed production (Biniak and Aldrich 1986; Brewer and Oliver 2007; Clay and Griffin 2000; Isaacs et al. 1989; Taylor and Oliver 1997; Walker and Oliver 2008). A 33% solution of glyphosate applied to velvetleaf and giant foxtail (*Seteria faberi* Herrm.) at early flower and heading, respectively, using a roller paint brush to simulate a roller or ropewick applicator reduced seed numbers at least 96% (Biniak and Aldrich 1986). Early flower and heading applications were in general more effective at reducing seed number, seed weight, and germination percentage than later application timings. For entireleaf morningglory, an application made 9 WAE, when plants were in early reproductive development reduced seed production 64, 88, and 93% from glyphosate rates of 0.42, 0.84, and 1.68 kg ae ha^{-1}, respectively (Brewer and Oliver 2007). Glyphosate applied at 0.28 kg ai ha^{-1} at early bloom (flowering without pods) reduced sicklepod seed production by 84% in 1984 and 100% in 1985 (Isaacs et al. 1989). Glyphosate rates of 0.21 kg ai ha^{-1} or greater applied to sicklepod at bud formation or flower to 9 cm pod stage reduced seed production 85% or more (Taylor and Oliver 1997). Glyphosate applied at 0.84 kg ae ha^{-1} to a complex of weeds when pitted morningglory (*Ipomoea lacunosa* L.) began flowering reduced seed production of Palmer amaranth (*Amaranthus palmeri* S. Wats.), barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], prickly sida, pitted morningglory (*Ipomoea lacunosa* L.), and sicklepod by 83, 88, 95, 98, and 99%, respectively (Walker and Oliver 2008).

Glyphosate applied at early fruit or later reproductive stages has also been shown to reduce weed seed production (Clay and Griffin 200; Isaacs et al. 1989; Taylor and Oliver 1997).

Glyphosate applied to sicklepod containing pods up to 5.5 cm in length reduced seed production 85%, but seed production was not reduced from applications made to sicklepod containing immature pods 9 cm or longer (Isaacs et al. 1989). Glyphosate at 0.84 kg ae ha^{-1} was required to reduce sicklepod seed production around 80% when applied at 15 to 30 cm pod development (Taylor and Oliver 1997). Hemp sesbania and common cocklebur (*Xanthium strumarium* L.) seed per plant was reduced 94 and 82%, respectively, when glyphosate was applied at initial seed set (75% of plants had set pods or burs 0-8 cm in length) (Clay and Griffin 2000). Sicklepod response to glyphosate applications at initial seed set was inconsistent, with no reduction in seed per plant or seedling emergence in the first year. In the second year, an initial seed set application reduced seed per plant 88% and seedling emergence 72%. Mid seed fill and physiological maturity applications of glyphosate were not effective in reducing seed number per plant for hemp sesbania, common cocklebur, or sicklepod.

Applications of auxinic herbicides to weeds just prior to flowering/anthesis, early flowering, and early fruit stage have been shown to reduce seed number and germination (Fawcett and Slife 1978; Isaacs et al. 1989; Jha and Norsworthy 2012; Maun and Cavers 1969; Taylor and Oliver 1997). Curly dock (*Rumex crispus* L.) exposed to 2,4-D 12 days before anthesis produced no viable seed (Maun and Cavers 1969). Plants that were exposed at anthesis produced seed with minute embryos that were not capable of germination and when exposed 7 days after anthesis only 5 to 15% of the seed were capable of germination. Seed production and germination were not reduced from exposure to 2,4-D 34 days after anthesis. Isaacs et al. (1989) reported that applications of 2,4-DB at 0.28 kg ai ha^{-1} and 2,4-D at 0.56 kg ai ha^{-1} to sicklepod at early bloom did not affect seed production, but applications at early fruit (full bloom and immature pods up to 5.5 cm long) reduced sicklepod seed numbers 96 and 34% for 2,4-DB and

2,4-D, respectively. Taylor and Oliver (1997) reported that dicamba at 1.1 and 2.2 kg ai ha^{-1} when applied to sicklepod at bud formation, flower to 9 cm pod stage, and 15 to 30 cm pod stage reduced seed number 78 to > 80%. For 2,4-D at of 0.6 and 1.1 kg ha^{-1} seed production was reduced 99 and 99%, respectively, for common lambsquarters (*Chenopodium album* L.) when applied prior to flowering; 77 and 84%, respectively, for redroot pigweed (*Amaranthus retroflexus* L.) when applied during flowering with some mature seed; and 64 and 100%, respectively, for jimsonweed (*Datura stramonium* L.) when applied at flowering (Fawcett and Slife 1978). In contrast, giant foxtail seed production was increased 307 and 381% from 0.6 and 1.1 kg ha^{-1} of 2,4-D, respectively, when applied prior to flowering. Although viability of common lambsquarters seeds produced was not greatly affected by 2,4-D, seedlings from seeds of plants treated with 2,4-D, were about half as vigorous as control plants. Additionally, jimsonweed seedling grown from seeds from 2,4-D treated plants exhibited phenoxy herbicide injury symptoms.

Herbicides have also been effective in reducing glyphosate-resistant Palmer amaranth seed production (Jha and Norsworthy 2012; Crow et al. 2015). Glufosinate (820 g ai ha^{-1}), 2,4-D (1060 g ae ha^{-1}), and dicamba (280 g ae ha^{-1}) applied at the first visible sign of inflorescence to glyphosate-resistant Palmer amaranth biotypes reduced seed production of LC biotype by 75 to 87% and of the MC biotype by 94 to 95% compared to the non-treated plants (Jha and Norsworthy 2012). Glufosinate, 2,4-D and glyphosate (870 g ai ha^{-1}) reduced 100 seed weight 22%, irrespective of the biotype and seed viability was 45 to 61% compared with 97% in the non-treated plants. All herbicides reduced cumulative seedling recruitment by an average of 84%.

Crow et al. (2015) evaluated after corn harvest (POST-harvest) weed management programs for Palmer amaranth control and seed production prevention. At the time of application weeds ranged from 6 to 50 cm with many of them beginning to flower. Paraquat at 840 g ai ha^{-1} alone or in combination with s-metolachlor (1070 g ai ha^{-1}), metribuzin (263 g ai ha^{-1}), pyroxasulfone (149 g ai ha^{-1}), saflufenacil (50 g ai ha^{-1}), flumioxazin (72 g ai ha^{-1}), pyroxasulfone + flumioxazin (70 and 89 g ai ha^{-1}), or pyroxasulfone plus fluthiacet (128 and 4 g ai ha^{-1}) controlled Palmer amaranth at least 91% 14 DAA. Paraquat applied with residual herbicides were more effective in reducing weed regrowth and new emergence compared with paraquat alone. All POST-harvest programs successfully prevented seed production of Palmer amaranth effectively, eliminating the addition of 1,200 seed m^{-2} or 12 million seed ha^{-1} return to the soil seedbank.

A 3% solution of chlorsulfuron applied to velvetleaf and giant foxtail at early flower and heading, respectively, using a roller paint brush to simulate a roller or ropewick applicator prevented velvetleaf from setting seed and reduced giant foxtail seed numbers 70% (Biniak and Aldrich 1986). Early flower and heading applications were in general more effective at reducing seed number, seed weight, and germination percentage than later application timings. Chlorimuron and imazaquin at 0.28 kg ai ha^{-1} applied to sicklepod at early bloom (flowering no pods) and early fruit (having immature pods up to 5.5 cm) almost eliminated seed production, and none of the seed produced were able to germinate (Isaacs et al. 1989). Glufosinate at 0.84 kg ai ha^{-1} reduced seed production greater than 80% when applied to sicklepod at bud formation, flowering to 9 cm pod, and 15 to 30 cm pod (Taylor and Oliver 1997). Paraquat was more effective than glufosinate and a paraquat rate of 0.26 kg ai ha^{-1} or higher reduced seed production greater than 80% at all application timings.

SHADING EFFECTS ON PLANT GROWTH AND REPRODUCTION

Light regulates plant growth and development through, photoperiod, quantity of total light and of photons, spectral quality, and duration (Holt 1995). Light influences the weed/crop ecosystem by regulating crop and weed growth and competition. Plant competitive ability is partly controlled by how efficient light is utilized for growth (Keeley and Thullen 1978; Santos et al. 1997). Irradiance, is determined by photoperiod and solar angle which varies with latitude and season, time of day, and prevailing weather (Holt 1995). Maximum growth and photosynthetic rates occur in full sunlight for most plants, and decrease upon reduced light. Changes in light level during the life cycle of a plant has profound effects on growth and development and is dependent on the plants ability to acclimate. Dall'Armellina and Zimdahl (1988) determined that total photosynthetic photon flux density was more important for growth and development of field bindweed (*Convolvulus arvensis* L.) regardless of whether it was exposed to low or high irradiance first early in its development.

Many weeds when transferred from high irradiance to a shaded environment, which occurs during crop canopy development and closure, react by adaptations that reduce the growth-limiting effects of shading (Holt 1995; Patterson 1980). Some plants can acclimate to reduced light situations by altering dry matter distribution and leaf anatomy, and by decreasing respiration rates, enzyme activities, and electron transport capacity (Holt 1995). Palmer amaranth showed morphological acclimation to shading by increasing specific leaf area (SLA) and decreasing leaf and main-stem branch appearance (Jha et al. 2008) and common waterhemp (*Amaranthus rudis* Sauer) responded to reduced irradiance by increasing leaf development at the expense of stem and seed and more time was required to accumulate biomass (Steckel et al.

2003). Also, time of weed emergence relative to the crop can affect its competition and response to environmental stress including reduced irradiance.

Bazzaz and Carlson (1982) determined that early successional annuals (weeds) were not only well adapted to high irradiance, but were also capable of coping with extreme variation in the light environment, becoming like shade plants in response to low irradiance. Holt (1995) postulated that the plasticity observed in early successional weed species in their photosynthetic response to light level may result in survival and reproduction in low light environments. Therefore, weed management thru manipulation of the light environment in a crop would be difficult. Manipulation of the crop canopy to improve weed management and crop yield can only be accomplished with an understanding of the dynamics of light competition with the weed/crop canopy and the role of weed plasticity response to changing light conditions.

Light is first intercepted in the drill where the crop is planted, followed by shoulders of planted beds and row middles/furrows (Keeley and Thullen 1978). Orientation of the planted drill (north to south, east to west) influences light interception in relation to the shoulders of beds, but differences become less pronounced as the crop canopy increases and intercepts more light. The rate of crop canopy development and interception of light varies with production practices and environmental conditions. Row spacing, plant population per hectare, date of planting, and inherent differences in vigor among crop varieties and hybrids will influence the level of crop light interception. Within 8 to 9 weeks after planting of corn 1 meter centers, interception of photosynthetically active radiation (PAR) was 90% or more. Because cotton and grain sorghum [*Sorghum bicolor* (L.) Moench *ssp. bicolor*] canopy development was slower than corn, 12 to 16 weeks was required to obtain 80% light interception. Depending on plant population (32,900 to 56,300 plants ha^{-1}), mean shade level measured in corn fields ranged from

92.4 to 97.3% (Knake 1972). An understanding of plants response to light and other environmental conditions can be used to develop weed management programs to exploit environmental interactions that favor crop competition with weeds (Dall'Armellina and Zimdahl 1988).

Bazzaz and Carlson (1982) measured photosynthetic flexibility as the difference in response between sun (full sunlight) and shade (approximately 1% of full sunlight) -grown plants. The following findings were reported 1) dark respiration rates for sun-grown plants were generally higher for early successional species than it was for mid- to late-successional species; 2) for both sun- and shade-adapted plants, quantum yield tended to be higher for the annuals than for the other species; 3) the light compensation point (light intensity at which net photosynthesis is zero) was generally higher for sun-grown plants than it was for plants grown in the shade; 4) the differences in light compensation points between shade- and sun-grown plants was higher for annuals than for late successional species. Also, all species were able to change their photosynthetic rate in response to light, from low photosynthetic rates when grown in the shade to higher rates when grown in full sunlight, and this change was greater for early successional annuals than for late successional species. Early successional annuals were high in photosynthetic flexibility, mid-successional species were intermediate, and late successional species were low. It was concluded that early successional species were both well adapted to higher irradiance found in early successional habitats and were better able to deal with extreme fluctuation in light level. The ability of early successional species to dramatically change their patterns of photosynthetic response to light level made them became more like shade plants when grown under shade (Bazzaz and Carlson 1982).

For giant foxtail grown under varying shade levels, plant height was similar for 0, 30, and 60% shade treatments (Knake 1972). As shade level increased internode length decreased for the first seven internodes. Giant foxtail under 30 and 60% shade maintained plant height, relative to no shade, with greater internode length for the eighth and ninth internodes. Number of stems per giant foxtail plant decreased with increasing shade, but even plants in 80% shade averaged 21 stems. Giant foxtail leaf number decreased with increasing shade level. In 0% shade plants averaged almost four new leaves a day until approximately 5 to 6 weeks after initiation of treatments when total leaf number reached 188 per plant. In contrast, giant foxtail in 80% shade produced new leaves for about 4 weeks where the number remained steady at about 40 leaves per plant thereafter. Dry weight decreased linearly with increasing shade level. Compared to no shade, 80% shade reduced number of seeds per head by 50% and seed weight by 70%.

As light quantity increased there was a direct proportional increase in average number of yellow nutsedge (*Cyperus esculentus* L.) shoots, tubers and total dry matter produced (Keeley and Thullen 1978). Thirty percent shade reduced dry matter and tuber production 32%. Yellow nutsedge height when grown in 30 to 80% shade was taller than that of plants grown in full sunlight or 94% shade. Dense shade (80 and 94% shade) did not prevent the formation of tubers and after 3 months, tubers population averaged 429 and 99 tubers per plot an average gain of 381 and 51 tubers compared with initial tuber population.

Dry weight of itchgrass [*Rottboellia cochinchinensis* (Lour.) W. D. Clayton] at 40 days after planting when grown in 2, 25, and 60% sunlight was 0.3, 16, and 55% of that for plants grown in full sunlight (Patterson 1979). Leaf area of itchgrass grown in 2, 25, and 60% sunlight was 2, 42 and 99% of that of plants growing in full sunlight. At 40 days after planting tiller production was not observed for 2% sunlight and was similar for the 100 and 60% sunlight treatments. Root/shoot ratios were greatest for plants in full sunlight (0.52) and those transferred from 2 to 100% (0.53) sunlight. Photosynthetic rates decreased with increasing shade. For recently expanded, single, fully exposed leaves, photosynthetic rates were 22.5, 51.6, and 65.5 mg CO_2 dm^{-2} h^{-1} in 25, 60, and 100% sunlight, respectively. Photosynthetic rates did not significantly differ at saturating irradiance for itchgrass grown in 25, 60 or 100% sunlight and ranged from 76.4 to 78 mg CO_2 dm^{-2} h^{-1}. Stomatal resistance to CO_2 flux also did not differ significantly among itchgrass plants grown in 100, 60, and 25% sunlight. This demonstrated that even when grown in shade, itchgrass maintained the capacity for high photosynthetic rates.

After 89 days, cogongrass [*Imperata cylindrica* (L.) Beauv.] on average produced, three times more than total dry weight and leaf area in full light compared to 56% full light and 20 times as much as in 115% full light (Patterson 1980). Shading significantly affected the distribution of plant biomass into leaves, stem, roots and rhizomes. As shading increased the distribution of plant biomass into leaves increased, but decreased for rhizomes. For cogongrass grown in 11% light and transferred to full light 39 days later, biomass was 16 times greater than for cogongrass plants that remained in 11% light. The transferred plants produced as many shoots and leaves and three-fourths as many rhizomes as plants that remained in full light.

Silverleaf nightshade (*Solanum elaeagnifolium* Cav.) seedlings did not emerge under 92% shade (Boyd and Murray 1982). Silverleaf nightshade seedlings, when exposed to 92% shade grew for only a short time but no plants survived. Silverleaf nightshade height declined with increasing shade density. Plants grown from seed produced more leaves in full sunlight than did plants grown in shade, and full sunlight plants produced an average of almost 2 leaves per day between July 10 and July 20. Plants growing under 63% shade, however, averaged less than one during the same time period. Established plants exhibited an almost linear decrease in dry matter production with increasing shade level. Established plants in full sunlight produced more than 7 times the dry matter as plants in 92% shade. It was concluded that a shade level between 63 and 97% would be necessary to prevent seed production.

For field bindweed either grown from seed or rhizome segments, each decrease in light level (520, 325 and 236 μmol/m^2/s or 74, 84, 88% shade) reduced flower number and leaf area (Dall'Armellina and Zimdahl 1988). High linear regression correlations, $r^2 = 0.95$ to 0.98, indicated that reduced light could be used to reduce field bindweed seed production. They concluded that plants grown from seed were more vigorous than those grown from rhizome segments and plants from seeds were less sensitive to shading and better able to overcome the stress of growth under low light. For Russian knapweed (*Centaurea repens* L.) each decrease in light intensity decreased shoot and root dry weight. Total photosynthetic photon flux density was more important for growth than whether low or high light level occurred first.

As shade level increased (0, 40, 60, and 80% shade) shoot and tuber number of yellow nutsedge and purple nutsedge (*Cyperus rotundus* L.) decreased (Santos et al. 1997). For both species, shade levels beyond 60% did not further decrease shoot and tuber production, and a linear relationship was observed between shading and dry biomass accumulation of shoots and tubers. For purple nutsedge shoot dry weight was decreased by exposure to 20% shade, with no further effect from higher shade levels. Shoot dry weight was decreased by an average of 76% when purple nutsedge was exposed to 40% or greater shade intensity. In contrast, yellow nutsedge dry weight did not differ between 0 and 20% shade, but there was a steady decrease in shoot dry weight from 40 to 80% shade. Purple nutsedge tuber dry weight decreased steadily as shade level increased, but did not differ for 60 and 80% shade. Yellow nutsedge tuber dry weight was not affected by 20% shade, but dry weight decreased from 40 to 80% shade.

Common cocklebur, jimsonweed, velvetleaf, and soybean exposure to reduced irradiance resulted in decreased leaf thickness and increased chlorophyll content and photosynthetic rate per unit leaf volume (Regnier et al. 1988). In field and growth chamber experiments, maximum photosynthetic rates were correlated to leaf thickness for all species. When plants were exposed to light intensities below 700 to 1000 μE m^{-2} s^{-1}, photosynthetic rates of plants grown at low irradiance (180 μE m^{-2} s^{-1}) were greater than those of their counterparts grown in 800 μE m^{-2} s^{-1}. They postulated that higher photosynthetic rates may partially explain lower dark respiration rates (nonphotorespiratory mitochondrial CO_2 release) per unit leaf volume exhibited by plants grown at 180 μE m^{-2} s^{-1}. For plants grown at high-irradiance, chloroplast shading may occur from thicker palisade mesophyll layer, which in turn would lead to lower light harvest per unit leaf volume when light is sub-saturating compared to thinner leaves of the low-irradiance grown plants (little chloroplast shading). This increased photosynthetic rate partially compensated for the limited irradiance conditions of the shade plants. Leaf area ratio (ratio of leaf area to plant weight; LAR) was greater for all species grown at low irradiance and increase averaged 112% and 53% for growth chamber and field grown plants, respectively. All species compensated for reduced irradiance during growth by increasing LAR and photosynthesis per unit leaf volume when exposed to low light intensities. In response to high irradiance, all species increased light-saturated photosynthetic rate per unit leaf area; this reaction is typical of sun-adapted plants. Changes in LAR and light-saturated photosynthetic rate per unit leaf area were due primarily to changes in leaf thickness.

Differences in velvetleaf plant height, number of leaves, or branches/plant were not observed for plants in 30% shade compared to full sunlight (Bello et al. 1995). Exposure to shade for 3 weeks was required before difference in plant height were observed. Average leaf number was reduced 89 and 70% by 76% shade in 1984 and 1985, respectively. Less than 8 branches per plant were produced by velvetleaf plants growing in 76% shade; approximately half the branches produced by plants in full sunlight and 30% shade. Branch formation was also delayed by one week when velvetleaf was grown in 76% shade. Neither time of flower initiation or capsule formation was affected by shading. Capsule number was reduced 63% and 90% by 30 and 75% shade treatments, respectively. Of interest is that plants grown in shade produced seed that broke dormancy earlier than seeds produced in shade. Seeds from plants grown in full sunlight were 20% less likely to germinate under favorable conditions than were seed from plants produced in shade.

For common waterhemp emerging in June, maximum dry matter accumulation decreased from 0, 40, and 68% shade and equaled 22, 17, 3 g g^{-1} d^{-1} (Steckel et al. 2003). For May emerging common waterhemp, the duration of growth increased 1.5, 2.7, and 2.2-fold compared to the June emergence date. For common waterhemp plants growing in 68% shade, the duration of growth was significantly longer than that of plants growing in 0 to 40% shade. This suggests that common waterhemp increases the duration of dry weight accumulation in response to low irradiance levels. Common waterhemp growing in low irradiance was able to produce viable seed indicating that even though dry matter accumulation was prolonged due to reduced irradiance, common waterhemp was still able to reach maturity under delayed emergence conditions. Shade treatments did not affect the maximum growth of common waterhemp plants emerging in June. However, shade treatments did affect the maximum growth rate of common waterhemp emerging in May, with the number of days to reach maximum growth rate increasing as shade intensity increased. Final plant height was not different for common waterhemp plants growing in 0, 40, and 68% shade. Dry matter produced by common waterhemp in full sunlight for early and late emergence was 720 and 350 g plant^{-1}, respectively. Biomass was reduced from each additional increase in shade by 24, 49 and 99% for the early emerging plants and 37, 51 and 99% for late emerging plants. Averaged over emergence dates, each additional increase in shade over full sunlight, reduced seed production 51, 75, and 99%. They concluded that common waterhemp responded to reduced irradiance by increasing leaf development at the expense of stem and seed and more time was required to accumulate biomass.

Light response curves for photosynthesis per unit leaf area were similar for Palmer amaranth plants growing in 0 and 47% shade, and increased as PAR increased (Jha et al. 2008). Leaves of plants grown in 0 and 47% light showed no evidence of light saturation at the highest PAR measured, 1,200 μmol/m^2/s. Plants growing under 87% shade acclimated by lowering light compensation point 24% compared to full sunlight. In response to 87% shade, Palmer amaranth SLA was increased 28 and 42% over 47 and 0% shade, respectively. Palmer amaranth compensated for reduced PAR by increasing leaf surface area per unit of leaf biomass which would permit greater harvest of PAR per leaf. Palmar amaranth's increase in SLA was concomitant with a decrease in light-saturated photosynthetic rates per unit leaf area. By producing thinner leaves Palmer amaranth lowered its light compensation point and dark respiration rate per unit leaf area. Leaf chlorophyll content of Palmer increased under 47% shade, however, chlorophyll content was similar between Palmer amaranth in full sunlight and 87% shade. The increased SLA of Palmer amaranth growing in 87% shade but the plants inability to increase leaf chlorophyll per unit leaf area caused reductions in the photosynthetic ability of those plants. In all shade treatments, Palmer amaranth height increased linearly with growing degree day (GDD), and the increase in plant height per GDD was not influenced by the decrease in PAR from shading. Palmer amaranth conserved limited assimilates and maintained growth under low photosynthetic rates by decreasing the leaf production rate with increasing shade intensity. In all shade treatments main-stem branch appearance increased linearly with increasing GDD, but the main-stem appearance rate differed among shade treatments. Reducing main-stem branch production, is a shade acclimation strategy of Palmer amaranth that allows for less vegetative biomass allocation to branch components that deplete photosynthates, thereby ensuring sufficient resources to meet the demands of reproductive development. They concluded that Palmer amaranth showed morphological acclimation to shading by increasing its SLA and decreasing leaf and main-stem branch appearance.

This research concentrates on prickly sida, a weed that can emerge in northeastern Louisiana in early March and that is becoming more problematic in crops. The shift in recent years toward earlier maturing crops has resulted in late-season prickly sida emergence both in-crop and in harvested fields. Associated seed production has contributed to increased prickly sida presence and competition with crops. This research on prickly sida specifically addresses 1) emergence periodicity from March through October in fields with silty clay loam and clay soils, 2) plant growth and seed production response to shade comparing gradual shade increase as would occur within a developing crop canopy and decrease in shade as would occur with crop senescence, 3) weed control and soybean yield using residual herbicides preplant, at-planting, and POST, and 4) POST harvest control programs to reduce seed production and seed viability using glyphosate and 2,4-D.

LITERATURE CITED

Baskin JM, Baskin CC (1984) Environmental conditions required for germination of prickly sida (*Sida spinosa*). Weed Sci. 32:786-791.

Bazzaz, FA, Carlson RW (1982) Photosynthetic acclimation to variability in the light environment of early and late successional plants. *Oecologia* 54:313-316.

Bello IA, Owen MDK, Hatterman-Valenti HM (1995) Effect of shade on velvetleaf (*Abutilon theophrasti*) growth, seed production, and dormancy. Weed Technol. 9:452-455.

Bennett AC, Shaw DR (2000) Effect of preharvest desiccants on weed seed production and viability. Weed Technol. 14:530-538.

Biniak BM, Aldrich RJ (1986) Reducing velvetleaf (*Abutilon theophrasti*) and giant foxtail (*Setaria faberi*) seed production with simulated-roller herbicide applications. Weed Sci 34:256-259.

Boyd JW, Murray DS (1982) Effects of shade on silverleaf nightshade (Solanum elaeagnifolium). Weed Sci 30:264-269.

Brewer CE, Oliver LR (2007) Reducing weed seed rain with late-season glyphosate applications. Weed Technol 21:753758.

Bryson CT, DeFelice MS (2009) Weeds of the South. University of Georgia Press, Athens, GA. Pp. 468.

Clay PA, Griffin JL (2000) Weed seed production and seedling emergence responses to late-season glyphosate applications. Weed Sci 48:481-486.

Crow WD, Steckel LE, Hayes RM, Mueller TC (2015) Evaluation of POST-harvest herbicide applications for seed prevention of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*). Weed Technol 29:405-411.

Dall'Armellina AA, Zimdahl RL (1988) Effect of light on growth and development of field bindweed (*Convolvulus arvensis*) and Russian knapweed (*Centaurea repens*). Weed Sci 36:779-783.

Davis AS (2008) Weed seed pool concurrent with corn and soybean harvest in Illinois. Weed Sci 56:503-508.

Egley GH (1976) Germination of developing prickly sida seeds. Weed Sci. 24:239-243.

Egley GH (1990) High-temperature effects on germination and survival of weed seeds in soil. Weed Sci. 38:429-435.

Egley GH, Chandler JM (1978) Germination and viability of weed seeds after 2.5 years in a 50-year buried seed study. Weed Sci. 26:230-239.

Egley GH, Chandler JM (1983) Longevity of weed seeds after 5.5 years in the Stoneville 50-year buried-seed study. Weed Sci. 31:264-270.

Fawcett RS, Slife FW (1978) Effects of 2,4-D and Dalapon on weed seed production and dormancy. Weed Sci 26:543-547.

Hartzler RG, Battles BA (2001). Reduced fitness of velvetleaf (*Abutilon theophrasti*) surviving glyphosate. Weed Technol 15:492-496.

Holt JS (1995) Plant responses to light: A potential tool for weed management. Weed Sci 43:474-482.

Hoveland CS, Buchanan GA (1973) Weed seed germination under simulated drought. Weed Sci 21:322-324.

Isaacs MA, Murdock EC, Toler JE, Wallace SU (1989) Effects of late-season herbicide applications on sicklepod (*Cassia obtusifolia*) seed production and viability. Weed Sci 37:761-765.

Jha P, Norsworthy JK (2012). Influence of late-season herbicide applications on control, fecundity, and progeny fitness of glyphosate-resistant palmer amaranth (*Amaranthus palmeri*) biotypes from Arkansas. Weed Technol 26:807-812.

Jha, P, Norsworthy JK, Riley MB, Bielenberg DG, Bridges Jr. W (2008) Acclimation of Palmer amaranth (*Amaranthus palmeri*) to shading. Weed Sci 56:729-734.

Jordan DL, York AC, Griffin JL, Clay PA, Vidrine PR, Reynolds DB (1997) Influence of application variables on efficacy of glyphosate. Weed Technol 11:354-362.

Keeley PE, Thullen RJ (1978) Light requirements of yellow nutsedge (*Cyperus esculentus*) and light interception by crops. Weed Sci 26:10-16.

Kegode GO, Forcella F, Clay S (1999) Influence of crop rotation, tillage, and management inputs on weed seed production. Weed Sci 47:175-183.

Knake EL (1972) Effect of shade on giant foxtail. Weed Sci 20:588-592.

Maun MA, Cavers PB (1969) Effects of 2,4-D on seed production and embryo development of curly dock. Weed Sci 17:533-536.

Patterson DT (1979) The effects of shading on the growth and photosynthetic capacity of itchgrass (*Rottboellia exaltata*). Weed Sci 47:549-553.

Patterson DT (1980) Shading effects on growth and partitioning of plant biomass in cogongrass (*Imperata cylindrical*) from shaded and exposed habitats. Weed Sci 28: 735-740.

Rankins Jr. A, Boyd Jr. JD, Mask DB, Barnett JW, Gerard PD (2005) Survey of soybean weeds in Mississippi. Weed Technol. 19:492-498.

Regnier EE, Salvucci ME, Stoller EW (1988). Photosynthesis and growth responses to irradiance in soybean (*Glycine max*) and three broadleaf weeds. Weed Sci 36:487-496.

Santos BM, Morales-Payan JP, Stall WM, Bewick TA, Shilling DG (1997) Effects of shading on the growth of yellow nutsedge (*Cyperus* spp.). Weed Sci 45:670-673.

Smith CA, Shaw DR, Newsom LJ (1992) Arrowleaf sida (*Sida rhombifolia*) and prickly sida (*Sida spinosa*): germination and emergence. Weed Res 32: 103-109.

Steckel LE, Sprague CL, Hager AG, Simmons FW, Bollero GA (2003) Effects of shading on common waterhemp (*Amaranthus rudis*) growth and development. Weed Sci 51:889-903.

Taylor SE, Oliver LR (1997) Sicklepod (*Senna obtusifolia*) seed production and viability as influenced by late-season postemergence herbicide applications. Weed Sci 45:497-501.

Thomas WE, Pline-Srnić WA, Viator RP, Wilcut JW (2005) Effects of glyphosate application timing and rate on sicklepod (*Senna obtusifolia*) fecundity. Weed Technol 19:55-61.

Walker ER, Oliver LR (2008) Weed seed production as influenced by glyphosate applications at flowering across a weed complex. Weed Technol 22:318-325.

Webster TM, Coble HD (1997) Changes in weed species composition of the Southern United States: 1974 to 1995. Weed Technol 11:308-317.

Webster TM, Nichols RL (2012) Changes in the prevalence of weed species in the major agronomic crops of the Southern United States: 1994/1995 to 2008/2009. Weed Sci 60:145-157.

Woodson Jr, RE, Schery RW, Robyns A (1965) Flora of Panama Part IV. Family 115 Malvaceae. Missouri Botanical Garden. 52:497-578.

CHAPTER 2
PRICKLY SIDA (SIDA SPINOSA) EMERGENCE PERIODICITY IN NORTHEASTERN LOUISIANA

INTRODUCTION

Prickly sida (*Sida spinosa* L.) is widely distributed in the southern U.S. and is a troublesome broadleaf weed in cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), peanut (*Arachis hypogaea* L.), and soybean [*Glycine max* (L.) Merr.] (Webster and Coble 1997; Webster and Nichols 2012). A survey of weeds in Mississippi found prickly sida present in 40% of soybean fields sampled, making it the most prevalent weed (Rankins et al. 2005). Prickly sida was reported as the most troublesome weed of cotton in 1974 and second most troublesome in 1983 (Webster and Coble 1997). By 2008 and 2009 prickly sida ranked as the 19th most troublesome weed in corn and soybean and 14th in cotton (Webster and Nichols 2012).

For prickly sida light was not a requirement for germination when either freshly mature scarified seed or unscarified seed were incubated at temperatures between 30 and 40 C (Baskin and Baskin 1984; Smith et al. 1992). Germination of prickly sida seeds transferred from 15/6, 20/10, 25/15, or 30/15 C to a higher regime of 20/10, 25/15, 30/15, or 40/25 C was greater than when maintained continuously at the lower temperature regime (Baskin and Baskin 1984). Wet/dry cycles also enhanced germination. Neither moist chilling at 5 C nor freezing and thawing stimulated prickly sida seed germination.

Crop canopy development can influence weed emergence by affecting both light quality and diurnal soil temperatures (Jha and Norsworthy 2009; Norsworthy 2004; Benech-Arnold et al. 1988). Meyers et al. (2004) observed that soil degree days were good predictors of emergence for common ragweed (*Ambrosia artemisiifolia* L.), common lambsquarters (*Chenopodium album* L.), velvetleaf (*Abutilon theophrasti* Medikus), giant foxtail (*Seteria faberi* Herrm.), yellow foxtail [*Seteria pumila* (L.) Beauv], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], smooth pigweed (*Amaranthus hybridus* L.), and eastern black nightshade (*Solanum ptycanthum* Dun.). Bagavathiannan et al. (2011), however, reported that growing degree days did not predict barnyardgrass emergence any better than calendar days. Stoller and Wax (1973) observed that for several weed species cumulative soil heat units above 10 C was not correlated with emergence initiation; instead initial emergence was attributed to stimuli associated with general soil warming.

Although tillage has not been shown to affect emergence periodicity, it can affect total seedling emergence (Anderson and Nielsen 1996; Egley and Williams 1990; Ogg and Dawson 1984). Egley and Williams (1991) reported that in most years prickly sida emerged during the midseason period and emergence periodicity was not affected by tillage at a 5 to 15 cm depth. Understanding the soil seed population and seedling emergence patterns associated with tillage systems may aid in predicting weed infestation levels in crops (Forcella et al. 1992). Knowledge of weed population dynamics would be useful in making weed management decisions (Jha and Norsworthy 2009; Myers et al. 2004; Norris 2007; Ogg and Dawson 1984). Weed species can vary in there emergence periodicity (Anderson and Nielsen 1996; Bagavathiannan et al. 2011; Eberlein et al. 1988; Egley and Williams 1991; Hilgenfeld et al. 2004; Ogg and Dawson 1984; Schwinghamer and Acker 2008; Stoller and Wax 1973) and in addition to light and temperature, seed dormancy status can also affect seasonal emergence (Baskin and Baskin 1985). Hilgenfeld et al. (2004) reported that ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.] and shattercane [*Sorghum bicolor* (L.)] have prolonged emergence periodicity and were capable of re-infesting fields following early season postemergence applications of glyphosate. Consequently, an integrated season long weed management plant would be critical to ensure that difficult to control weeds do not proliferate.

A five-year study at Stoneville, MS, evaluated weed emergence where reseeding was restricted to allow for comparison of emergence patterns from only seed present in the soil (Egley and Williams 1991). For prickly sida, initial emergence occurred from early April to early May and peak emergence occurred between late-May and early-August. In Louisiana, prickly sida has emerged as early as the first week of March and has been observed to persist under a corn canopy and to germinate after corn harvest. A study was conducted to investigate prickly sida emergence periodicity in Northeastern Louisiana on silty clay loam and clay soils.

MATERIALS AND METHODS

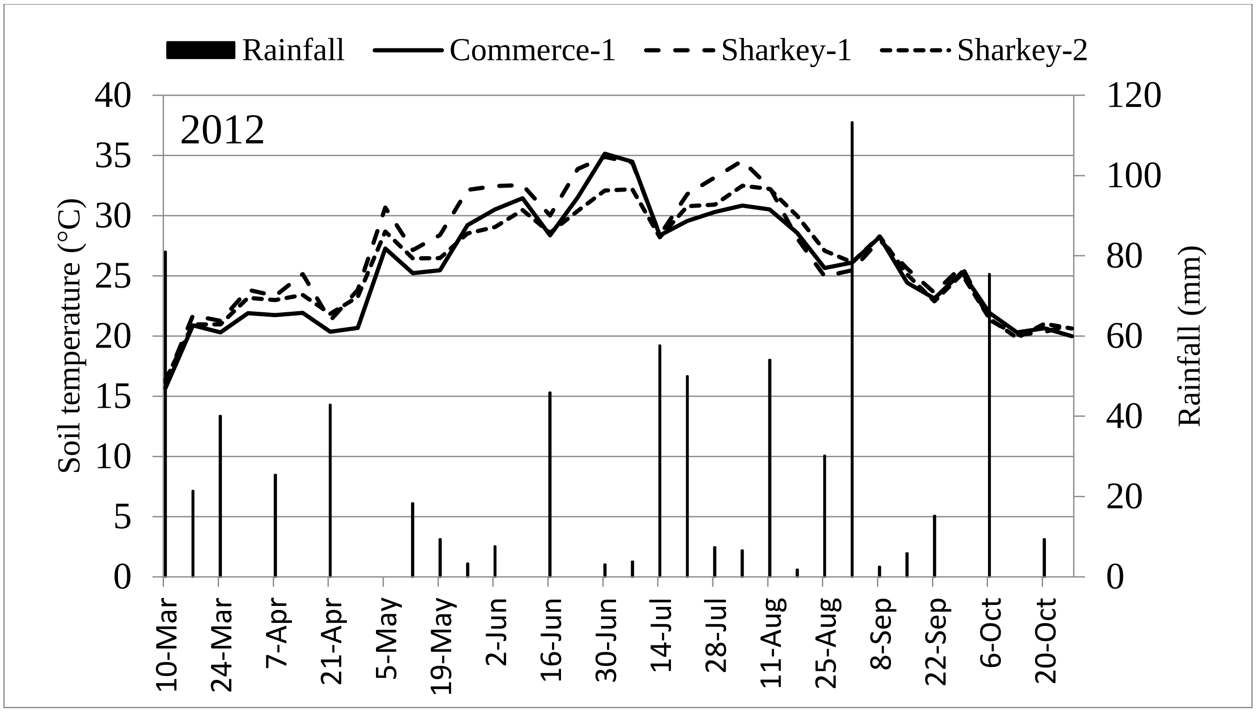
A study was conducted in 2012 and 2013, at the LSU AgCenter Northeast Research Station (NERS) near St. Joseph, La. In 2012, three field sites were used: one a Commerce silty clay loam soil (fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts) with no fall seedbed preparation (Commerce-1) and the other two a Sharkey clay soil (very-fine, smectitic, thermic Chromic Epiaquerts) with seedbed preparation the previous fall (Sharkey-1 and Sharkey-2). In 2013, two field sites were used: a Commerce silty clay loam soil with no fall seedbed preparation (Commerce-2) and a Sharkey clay soil with fall seedbed preparation (Sharkey-3). Each field site was selected based on presence of a natural prickly sida population.

Six 1 m^{-2} randomly assigned plots at each site were flagged and used to collect prickly sida emergence data. Data collection was initiated on March 2, 2012 and on March 17, 2013 and continued every 14 days until October 23, 2012 and October 17, 2013. Immediately following data collection at each date plots were treated with paraquat (Gramoxone SL, Syngenta Crop Protection LLC, Greensboro, NC 24719) at 560 g ai ha^{-1} plus 1% v/v crop oil concentrate (COC)

(Superb HC, Winfield Solutions LLC, St. Paul, MN 55164) to remove all vegetation. Because prickly sida seedling and other weeds were less than 5 cm, paraquat completely controlled all vegetation present.

Daily rainfall data for both years were obtained from the NERS weather station located approximately 1 mile from the experimental sites. In 2012, soil temperature data one week prior to prickly sida emergence were collected from the weather station and thereafter at each site using WatchDog B101 8K Temp data loggers (Spectrum Technologies Inc., Aurora, IL 60504) placed at a 3.8 cm depth and set to record every hour. In 2013, soil temperature was determined using data loggers at the Commerce site and at the NERS weather station. Weekly total rainfall and weekly average soil temperature data for 2012 and 2013 for each site are presented in Figure 2.1.

Actual prickly sida emergence data at each collection date and calculated cumulative data across the growing season were subjected to ANOVA using Standard Least Squares method in Fit Model functionality in JMP® software (JMP 2015). Because the effect of variation in soil seed bank levels and rainfall is confounded with the effect of soil type, data were analyzed separately for each site-year combination as a completely randomized design (CRD) with date as fixed effect and the six areas within each site-year as replications. Type III tests were used to test significance of fixed effects. LSMEANS were used to compare actual and cumulative emergence at different dates and Fisher's protected LSD was used for mean separation. Data are presented in Tables 2.1 and 2.2. Actual and cumulative means plotted against date are presented in Figures 2.2 and 2.3. For the plotted cumulative data, standard error bars for each date are included to show the variation among the six replicates. In other research evaluating emergence periodicity



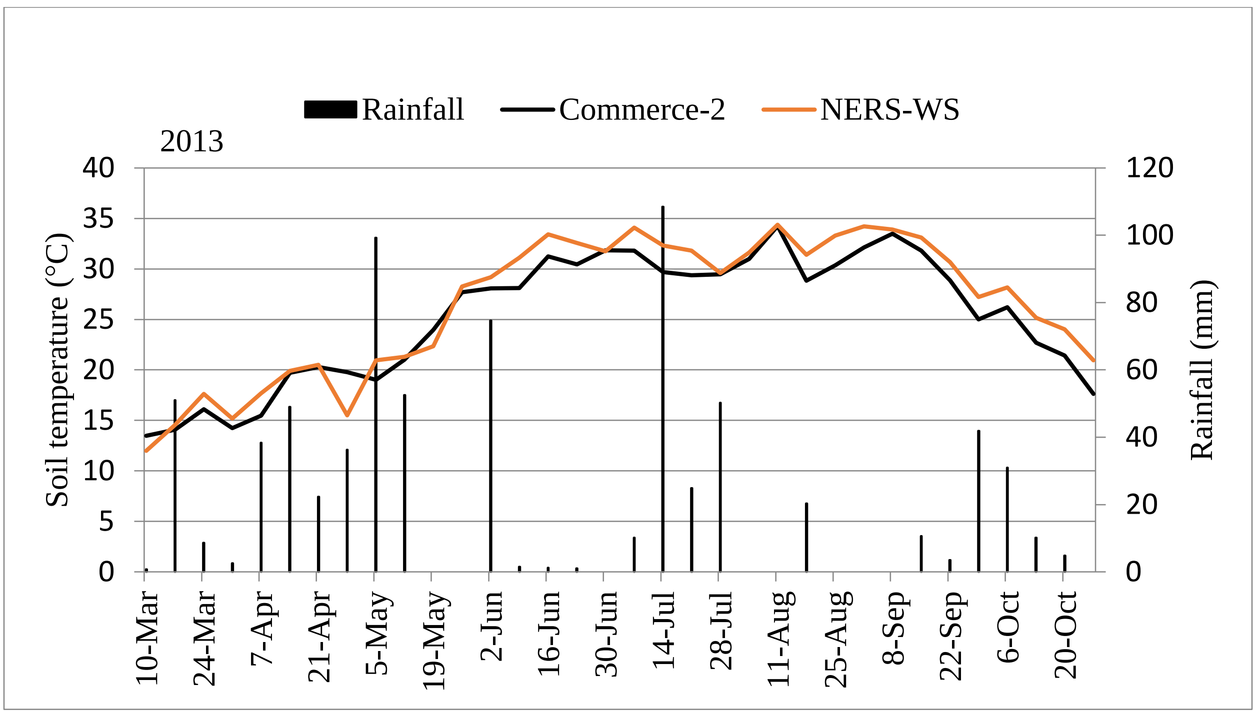


Figure 2.1. Total weekly rainfall data for 2012 and 2013 (vertical bars) obtained from the Northeast Research Station (NERS) weather station located approximately one mile from the experimental sites and average soil temperature in 2012 for the Commerce silty clay loam (Commerce-1) and Sharkey clay sites (Sharkey-1 and Sharkey-2) and in 2013 for the Commerce site (Commerce-2) and the NERS weather station.

Table 2.1. Actual and cumulative prickly sida emergence from March through October of 2012 at three sites at the Northeast Research Station, St. Joseph, LA on a Commerce silty clay loam soil (Commerce-1) and Sharkey clay soil (Sharkey-1 and Sharkey-2).

Commerce-1			Sharkey-1			Sharkey-2		
	Prickly sida (no. m^{-2})			Prickly sida (no. m^{-2})			Prickly sida (no. m^{-2})	
Collection date	Actual	Cumulative	Collection date	Actual	Cumulative	Collection date	Actual	Cumulative
3/2/2012	41 de[1]	41 f[1]	3/2/2012	41 cd	41 e	3/2/2012	2 c	2 f
3/10/2012	48 de	88 ef	3/10/2012	7 cd	48 e	3/10/2012	1 c	2 f
3/16/2012	279 c	367 e	3/16/2012	104 bc	152 de	3/16/2012	23 bc	25 f
3/23/2012	338 c	706 d	3/23/2012	36 cd	188 cde	3/23/2012	26 bc	51 f
3/31/2012	115 d	820 d	3/31/2012	52 cd	240 cde	3/31/2012	16 bc	67 f
4/8/2012	57 de	877 d	4/8/2012	38 cd	278 cde	4/8/2012	98 b	165 f
4/23/2012	55 de	932 d	4/23/2012	20 cd	298 cde	4/23/2012	19 bc	184 f
5/1/2012	0 e	932 d	5/1/2012	8 cd	306 cde	5/1/2012	4 c	188 def
5/14/2012	378 c	1310 c	5/14/2012	181 b	487 bcd	5/14/2012	289 a	476 cde
5/30/2012	7 de	1317 c	5/30/2012	1 d	487 bcd	5/30/2012	1 c	477 cde
6/4/2012	31 de	1348 c	6/4/2012	10 cd	497 bc	6/4/2012	0 c	477 cde
6/18/2012	629 b	1976 b	6/18/2012	187 b	684 b	6/18/2012	8 c	485 bcd
7/20/2012	943 a	2919 a	7/20/2012	563 a	1246 a	7/20/2012	275 a	761 abc
8/3/2012	8 de	2927 a	8/3/2012	1 d	1247 a	8/3/2012	22 bc	783 ab
8/28/2012	55 de	2982 a	8/28/2012	1 d	1249 a	8/28/2012	2 c	785 ab
9/13/2012	10 de	2992 a	9/13/2012	3 d	1252 a	9/13/2012	5 c	790 a
9/24/2012	3 de	2995 a	9/24/2012	1 d	1253 a	9/24/2012	2 c	791 a
10/23/2012	0 e	2995 a	10/23/2012	0 d	1253 a	10/23/2012	0 c	792 a

[1]Means within each column followed by a common letter are not significantly different using Fisher's protected LSD at P = 0.05.

Table 2.2. Actual and cumulative prickly sida emergence from March through October of 2013 at two sites at the Northeast Research Station, St. Joseph, LA on a Commerce silty clay loam soil (Commerce-2) and Sharkey clay soil (Sharkey-3).

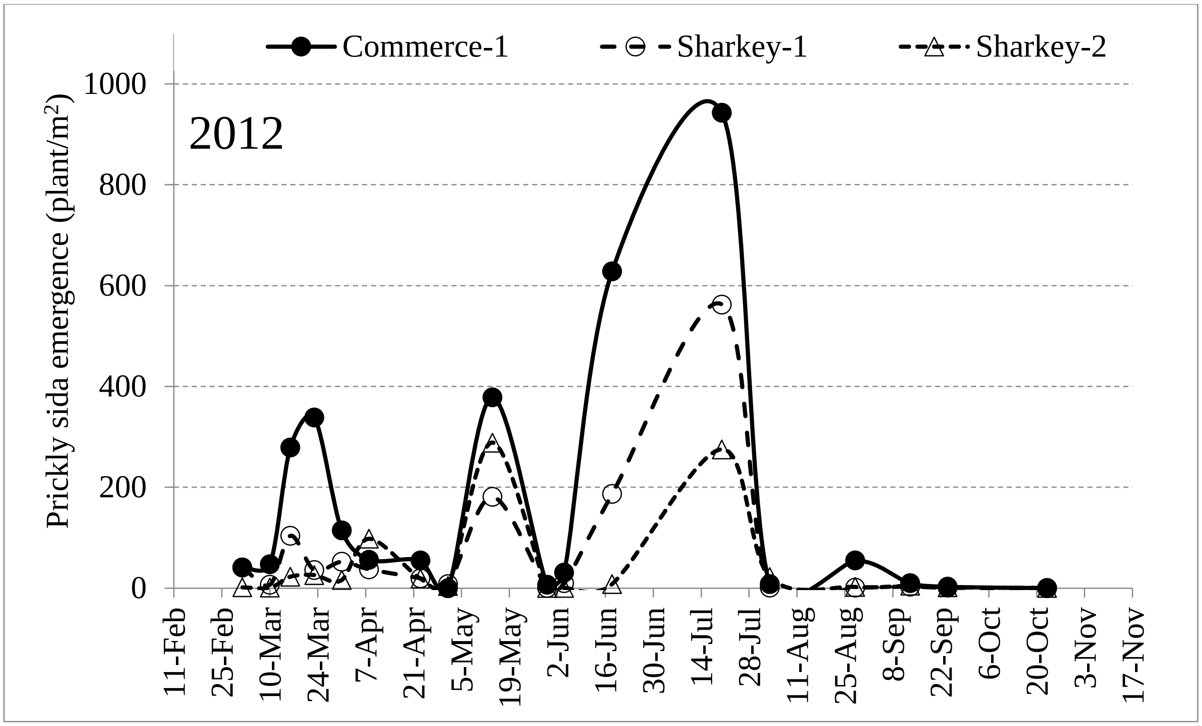
Commerce-2			Sharkey-3		
	Prickly sida (no. m^{-2})			Prickly sida (no. m^{-2})	
Collection date	Actual	Cumulative	Collection date	Actual	Cumulative
3/17/2013	0 d[1]	0 d[1]	3/17/2013	1 ef	1 g
4/1/2013	0 d	0 d	4/1/2013	10 def	11 g
4/8/2013	6 d	7 d	4/8/2013	30 def	41 g
4/23/2013	0 d	7 d	4/23/2013	147 a	188 f
5/6/2013	0 d	7 d	5/6/2013	158 a	346 e
5/20/2013	0 d	7 d	5/20/2013	67 c	413 e
6/3/2013	261 a	268 c	6/3/2013	173 a	586 d
6/17/2013	105 bc	372 c	6/17/2013	31 de	617 cd
7/1/2013	122 b	495 bc	7/1/2013	88 bc	705 bc
7/15/2013	112 bc	607 b	7/15/2013	111 b	815 ab
7/29/2013	4 d	611 b	7/29/2013	29 def	845 a
8/12/2013	3 d	614 b	8/12/2013	4 def	849 a
8/26/2013	40 cd	653 b	8/26/2013	33 d	881 a
9/9/2013	0 d	653 b	9/9/2013	0 f	881 a
10/2/2013	329 a	982 a	10/2/2013	13 def	895 a
10/17/2013	21 d	1003 a	10/17/2013	2 ef	896 a

[1]Means within each column followed by a common letter are not significantly different using Fisher's protected LSD at P = 0.05.

for six weeds, statistical analysis consisted of comparing emergence for each individual weed across the season using LSD (Egley and Williams 1991).

RESULTS AND DISCUSSION

Prickly sida emergence in 2012 was first observed on March 2 at all sites and averaged 41, 41, and 2 plant m^{-2} for Commerce-1, Sharkey-1, and Sharkey-2 sites, respectively (Table 2.1). In 2013, emergence was first observed on April 8 at the Commerce-2 site with 6 plant m^{-2} and on March 17 at the Sharkey-3 site with1 plant m^{-2} (Table 2.2). Seedling emergence had ceased by late October both years. In contrast to findings reported by Egley and Williams (1991) at Stoneville, MS, prickly sida emergence in the present study was initiated around 4 weeks earlier and ceased around 6 weeks later.



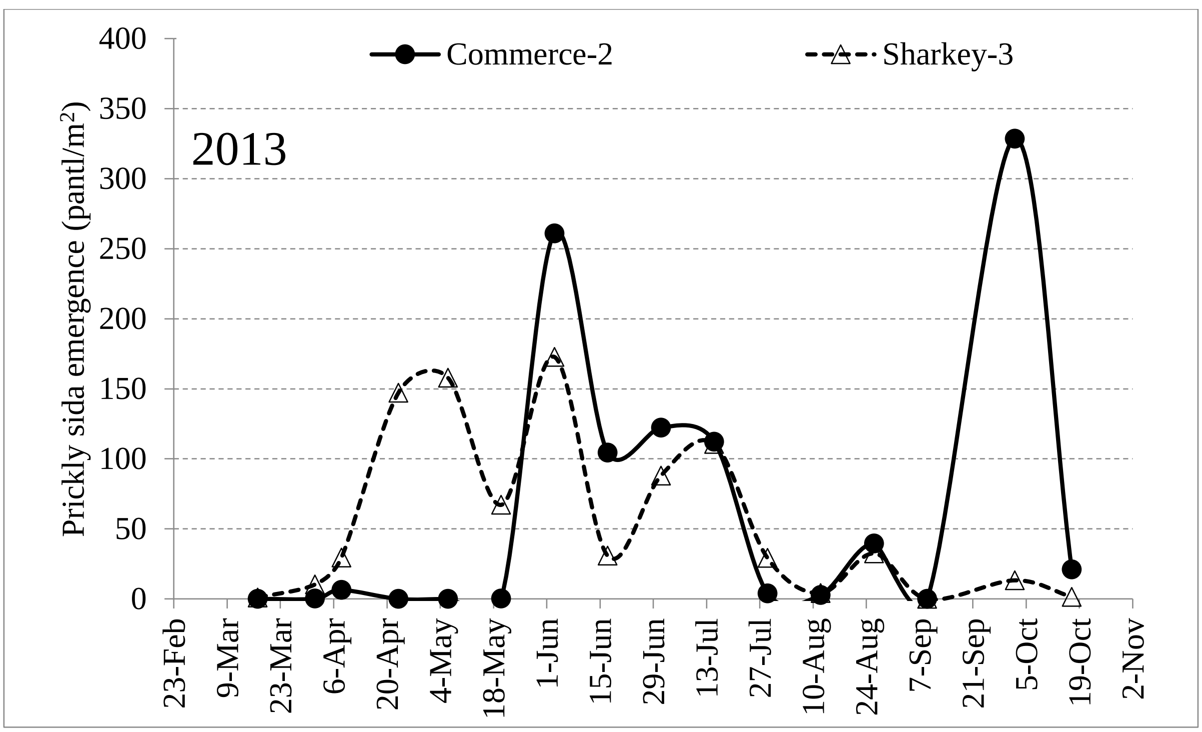
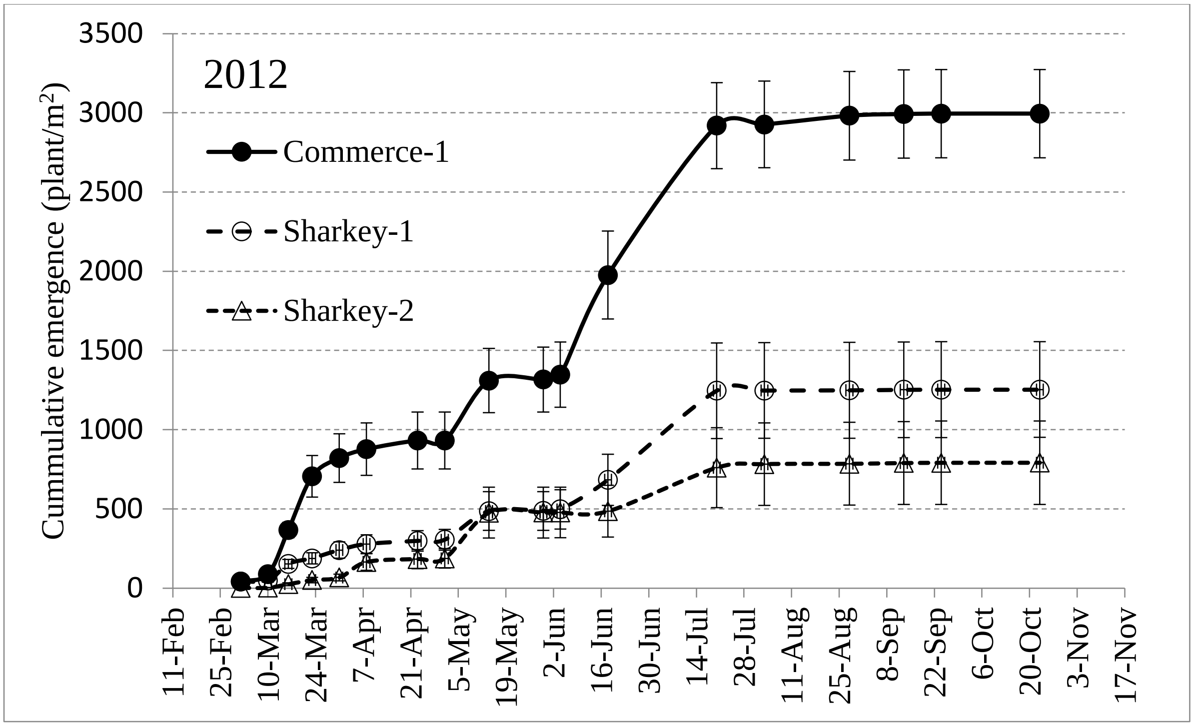


Figure 2.2. Emergence periodicity of prickly sida from March through October at three sites on the Northeast Research Station in 2012: Commerce silty clay loam (Commerce-1) and Sharkey clay (Sharkey-1 and Sharkey-2) and at two sites in 2013 (Commerce-2 and Sharkey-3).



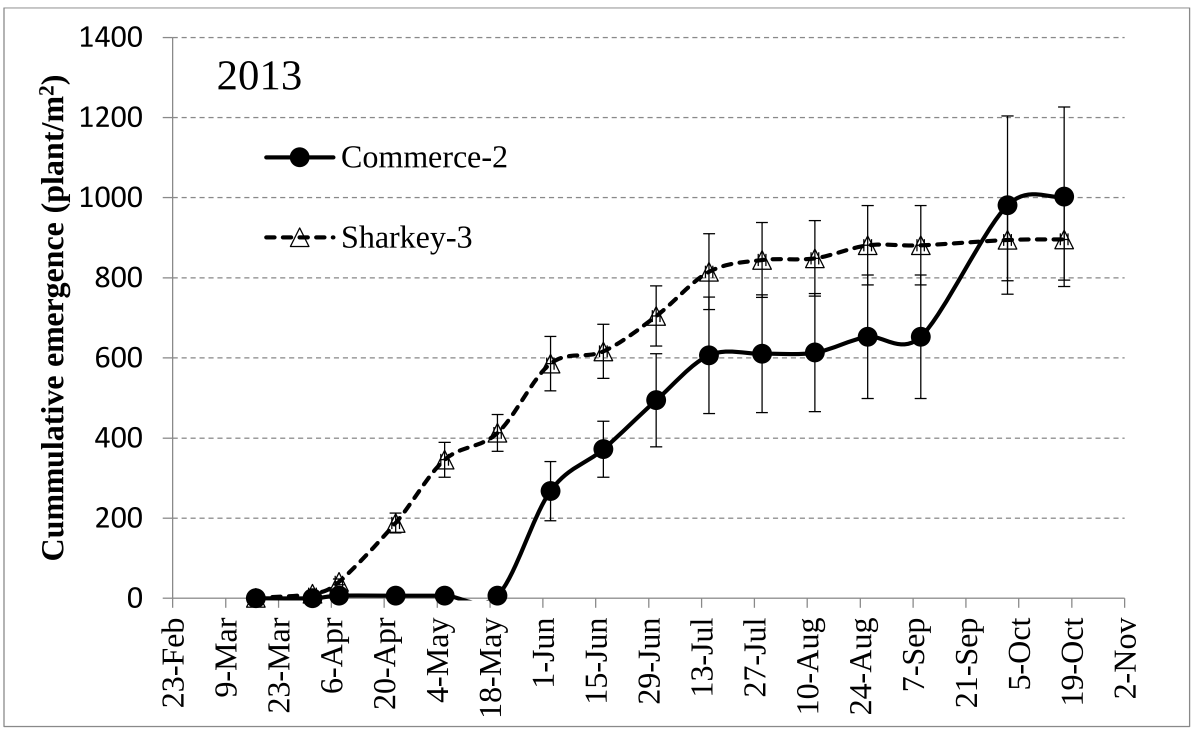


Figure 2.3. Cumulative emergence of prickly sida from March through October at three sites on the Northeast Research Station in 2012: Commerce silty clay loam (Commerce-1) and Sharkey clay (Sharkey-1 and Sharkey-2) and at two sites in 2013 (Commerce-2 and Sharkey-3). Standard error bars included to denote variability.

In 2012, for the Commerce site, increased emergence of prickly sida emergence occurred at five periods during March through October corresponding to March 16, March 23, (279, 338, and plants m^{-2}, respectively); May 14 (378 plants m^{-2}); and June 18 and July 20 (629 and 943 plants m^{-2}, respectively) (Table 2.1 and Figure 2.2). For the Sharkey sites in 2012 peak emergence periods occurred on May 14 for Sharkey-1 and Sharkey-2 (181 plants m^{-2} and 289 plants m^{-2}, respectively); June 18 for Sharkey-1 (187 plants m^{-2}); and July 20 for Sharkey-1 and Sharkey-2 (563 plants m^{-2} and 275 plants m^{-2}, respectively).

Rainfall in 2012 from March 4 through October 23 totaled 732 mm (Figure 2.1). For the three sites in 2012 the greatest increase in prickly sida emergence occurred on March 23 (Commerce site only) and on May 14 and July 20 for all sites. For the 3 weeks preceding March 23, 143 mm of rain was received. Rainfall of 18 and 108 mm was received during the two week period prior to May 14 and July 20, respectively.

In 2013 for the Commerce-2 site, increased emergence of prickly sida occurred on June 3 and June 17 (261 and 105 plants m^{-2}, respectively); July 1 and July 15 (122 and 112 plants m^{-2}, respectively); August 26 (40 plants m^{-2}); and October 2 (329 plants m^{-2}) (Table 2.2 and Figure 2.2). For the Sharkey-3 site in 2013, emergence peaks occurred on April 23 (147 plants m^{-2}); May 6 and 20 (158 and 67 plants m^{-2}, respectively); June 3 (173 plants m^{-2}); and July 1 and July 15 (88 plants and 111 plants m^{-2}, respectively). The large peak in emergence observed on October 2 for the Commerce-2 site, corresponded to only a slight increase (13 plants m^{-2}) for the Sharkey site. The increased emergence of prickly sida observed at both sites in late May and early June was also reported in research conducted in Mississippi (Egley and Williams 1991).

Rainfall in 2013 from March 4 through October 23 totaled 756 mm (Figure 2.1). The greatest increases in prickly sida emergence occurred on April 23 and May 6 at the Sharkey-3 site; on June 3, July 1, and July 15 at both sites; and on October 2 at the Commerce-2 site. For the three weeks preceding April 23, 110 mm of rainfall was received and for the 2 weeks preceding May 6, 136 mm was received. One week preceding the June 3 sampling, 75 mm of rain was received and from July 1 through July 15 rainfall totaled 119 mm. During the two weeks prior to the October 2 data collection at the Commerce-2 site a total of 73 mm of rain was received. It is noteworthy that from August 19 through September 22 only 14 mm of rainfall was received. Dry conditions followed by wet conditions have been shown to enhance prickly sida seed germination (Baskin and Baskin 1984). The reason for the large flush occurring at only the Commerce-2 site, is unclear and may be related soil texture and water holding capacity as well as differences in initial seed population and age, biological status, and stage of dormancy of the seed in the soil.

Weekly average soil temperature at the NERS weather station one week prior to prickly sida emergence was 16.5 C in 2012 and 14.2 C in 2013 (data no shown). In 2013, the soil temperature average recorded by data loggers at the Commerce site one week prior to prickly sida emergence was 13.8 C (Figure 2.1). Results show that prickly sida can emerge in the field when average soil temperature at a 3.8 cm depth is 13.8 C. Little information is available concerning the relationship between field soil temperature and prickly sida emergence. Egley (1976) reported that under laboratory conditions 18% of mature prickly sida seed were capable of germination when seed was stored at 25 C for 9 months to break dormancy followed by dark incubation for 7 d at 15 C. In another study, germination of prickly sida seed was 42% after seed were held in dry storage in the laboratory for 12 weeks and subjected to alternating temperatures of 15/6 C (12 h/12 h) for 30 days (Baskin and Baskin 1984). Results of the current study show that prickly sida is capable of emerging in the field under similar temperatures as those found in the previous studies.

In 2012, cumulative emergence of prickly sida from March 2 through October 23 was 2,995 seedlings m^{-2} for the Commerce site and 1,253 and 792 seedlings m^{-2} for the two Sharkey sites (Table 2.1 and Figure 2.3). Cumulative emergence was consistently greatest for the Commerce site compared with the Sharkey sites. It should be noted that unlike the Sharkey sites the Commerce site was not tilled in the fall. Egley and Williams (1990) evaluated weed emergence during a 5-year period where reseeding was prevented and found that in the first year, emergence of seven weeds was greater for non-tilled compared with tillage. In subsequent years tillage did not affect weed emergence. Although tillage has not been shown to affect emergence periodicity, it can affect total seedling emergence (Anderson and Nielsen 1996; Egley and Williams 1990; Ogg and Dawson 1984). For the Commerce site, 31% of the total prickly sida emergence for the season occurred from March 2 to April 23, 66% occurred from May 1 to July 20, and 3% occurred from August 3 to September 24. For the Sharkey sites prickly sida emergence from early March until early June was fairly consistent and 23% of the total prickly sida emergence for the season occurred from March 2 to April 23. From May 1 to July 20, approximately 75 % of the total prickly emergence occurred for the season at both Sharkey sites. From August 3 to September 24 less than 5% of the total prickly sida emergence for the season occurred at the Sharkey sites.

In contrast to 2012, cumulative emergence at the two sites from March 17 through early September 2013 was greatest for the Sharkey site (Table 2.1 and Figure 2.3). The large increase in prickly sida emergence at the Commerce site on October 2 (329 plants m^{-}2), however, resulted in total cumulative emergence in 2013 being greatest for the Commerce site (1,003 plants m^{-2}

compared with 896 plants m^{-2} for the Sharkey site). The reasons for the large increase in seedling emergence on October 2 at the Commerce site with only a slight increase at the Sharkey site was discussed previously. Based on total prickly sida seedling emergence for the growing season at the Commerce site, less than 0.7% occurred from March 17 to May 20, 60% from June 3 to July 29, and 39% from August 12 to October 17. Wet conditions from standing water and poor drainage resulted in this low emergence percentage for March 17 to May 20 (Figure 2.1). For Sharkey site prickly sida emergence was 46% of the total emergence from March 17 to May 20, 48% from June 3 to July 29, and less than 6% from August 12 to October 17.

Results show that in both 2012 and 2013 regardless of soil type, prickly sida was able to emerge when average soil temperature at a 3.8 cm depth was approximately 15 C and emergence continued through early October. Total prickly sida emergence in 2012 from March through October averaged 193% (3 times) more for the Commerce compared with the Sharkey sites. In 2013, total emergence from March through October was only 12% more for the Sharkey compared with the Commerce site. The Commerce site was not tilled in the fall either year of the study and the Sharkey sites were tilled in the fall both years. This disagreement in cumulative emergence between years for the Commerce silty clay loam and the Sharkey clay sites suggests that tillage was not a major factor affecting prickly sida emergence periodicity. Several studies report that tillage has no influence on weed emergernce periodicity (Anderson and Nielsen 1996; Egley and Williams 1990; Ogg and Dawson 1984). The prolonged emergence period for prickly sida support the need for a season long integrated weed management plan that reduces competition with the crop and seed production potential.

LITERATURE CITED

Anderson RL, Nielsen DC (1996) Emergence pattern of five weeds in the Central Great Plains. Weed Technol 10:744-749.

Bagavathiannan MV, Norsworthy JK, Smith KL, Burgos N (2011). Seedbank size and emergence pattern of barnyardgrass (*Echinochloa crus-galli*) in Arkansas. Weed Sci 59:359-365.

Baskin JM, Baskin CC (1984) Environmental conditions required for germination of prickly sida (*Sida spinosa*). Weed Sci 32:786-791.

Baskin JM, Baskin CC (1985) The annual dormancy cycle in buried weed seeds: A continuum. Bioscience 35:492-498.

Benech-Arnold RL, Ghersa CM, SaÂnchez RA, GarcõÂa Fernandez A (1988). The role of fluctuating temperatures in the germination and establishment of *S. halepense* (L.) Pers. Regulation of germination under leaf canopies. Funct Ecol 2:311-318.

Eberlein CV, Miller TL, Lurvey EL (1988). Seasonal emergence and growth of sorghum almum. Weed Technol 2:275-281.

Egley GH (1976) Germination of developing prickly sida seeds. Weed Sci 24:239-243.

Egley GH, Williams RD (1990) Decline of weed seeds and seedling emergence over five years as affected by soil disturbances. Weed Sci 38-504-510.

Egley GH, Williams RD (1991) Emergence periodicity of six summer annual weed species. Weed Sci 39:595-600.

Forcella F, Wilson RG, Renner KA, Dekker J, Harvey RG, Alm DA, Buhler DD, Cardina J (1992) Weed seedbanks of the U.S. Corn Belt: Magnitude, variation, emergence, and application. Weed Sci 40:636-644.

Hilgenfeld KL, Martin AR, Mortensen DA, Mason SC (2004) Weed management in glyphosate resistant soybean: Weed emergence patterns in relation to glyphosate treatment timing. Weed Technol 18:277-283.

Jha P, Norsworthy JK (2009) Soybean canopy and tillage effects on emergence of Palmer amaranth (*Amaranthus palmeri*) from a natural seed bank. Weed Sci 57:644-651.

JMP® 2015, Version 12.0.0. SAS Institute Inc., Cary, NC, 1989-20.

Myers MW. Curran WS, VanGessel MJ, Calvin DD, Mortensen DA, Majek BA, Karsten HD, Roth GW (2004) Predicting weed emergence for eight annual species in the northeastern United States. Weed Sci 52:913-919.

Norris RF (2007) Weed fecundity: Current status and future needs. Crop Prot 26:182-188.

Norsworthy JK (2004) Soybean canopy formation effects on pitted morningglory (*Ipomoea lacunosa*), common cocklebur (*Xanthium strumarium*), and sicklepod (*Senna obtusifolia*) emergence. Weed Sci 52:954-960.

Ogg, Jr. AG, Dawson JH (1984) Time of emergence of eight weed species. Weed Sci 32:327-335.

Rankins Jr. A, Boyd Jr. JD, Mask DB, Barnett JW, Gerard PD (2005) Survey of soybean weeds in Mississippi. Weed Technol. 19:492-498.

Schwinghamer TD, Van Acker RC (2008) Emergence timing and persistence of kochia (*Kochia scoparia*). Weed Sci 56:37-41.

Smith CA, Shaw DR, Newsom LJ (1992) Arrowleaf sida (*Sida rhombifolia*) and prickly sida (*Sida spinosa*): germination and emergence. Weed Res 32: 103-109.

Stoller EW, Wax LM (1973). Periodicity of germination and emergence of some annual weeds. Weed Sci 21:574-580.

Webster TM, Coble HD (1997) Changes in weed species composition of the Southern United States: 1974 to 1995. Weed Technol 11:308-317.

Webster TM, Nichols RL (2012) Changes in the prevalence of weed species in the major agronomic crops of the Southern United States: 1994/1995 to 2008/2009. Weed Sci 60:145-157.

CHAPTER 3
PRICKLY SIDA (SIDA SPINOSA) GROWTH AND SEED PRODUCTION AS INFLUENCED BY SHADE

INTRODUCTION

Prickly sida (*Sida spinosa* L.) is widely distributed in the southern U.S. and is a troublesome broadleaf weed in cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), peanut (*Arachis hypogaea* L.), and soybean [(*Glycine max* (L.) Merr.] (Webster and Coble 1997; Webster and Nichols 2012). A Mississippi survey of weeds conducted by Rankins et al. (2005) found prickly sida present in 40% of soybean fields sampled, making it the most prevalent weed. Prickly sida was present in 45% of soybean fields in the Delta region, compared with 43% in eastern Mississippi. In 2008 and 2009, prickly sida ranked as the 19th most troublesome weed in corn and soybean and 14th in cotton (Webster and Nichols 2012). In recent years in Louisiana, growers and consultants have reported increased problems with control of prickly sida in soybean (Bill Williams, personal communication). Glyphosate, the foundation herbicide of most weed control programs in corn, cotton, and soybean, and is most effective when applied to one- to three-leaves compared with four or more leaves prickly sida (Jordan et al. 1997).

Light regulates plant growth and development through, photoperiod, quantity of total light, spectral quality, and duration (Holt 1995). Light influences the weed/crop ecosystem by regulating crop and weed growth and competition. Plant competitive ability is partly controlled by efficiency in light utilized for growth (Keeley and Thullen 1978; Santos et al. 1997). Bazzaz and Carlson (1982) determined that early successional annuals (weeds) were not only well adapted to high irradiance, but were also capable of coping with extreme variation in the light environment, becoming like shade plants in response to low irradiance. Holt (1995) postulated that the plasticity observed in early successional weed species in their photosynthetic response to light level may result in survival and reproduction in low light environments.

Because of the adaptability of weeds, managing the light environment in a crop as a means to manage weeds would be difficult (Holt 1995). Manipulation of the crop canopy to improve weed management and crop yield can only be accomplished with an understanding of the light competition dynamics of the weed/crop canopy and the role of weed plasticity response to changing light conditions. An understanding of plants response to light and other environmental conditions can be used to develop weed management programs to exploit environmental interactions that favor crop competition with weeds (Dall'Armellina and Zimdahl 1988).

Maximum growth and photosynthetic rates occur in full sunlight for most plants, and decrease upon reduced light (Holt 1995). Many weeds when transferred from high irradiance to a shaded environment, which occurs during crop canopy development and closure, react by adaptations that reduce the growth-limiting effects of shading (Holt 1995; Patterson 1980). Some plants can acclimate to reduced light situations by altering dry matter distribution and leaf anatomy, and by decreasing respiration rates, enzyme activities, and electron transport capacity (Holt 1995). Palmer amaranth (*Amaranthus palmeri* S. Wats.) acclimated to shading by increasing specific leaf area (SLA) and decreasing leaf and main-stem branch appearance (Jha et al. 2008). Common waterhemp (*Amaranthus rudis* Sauer) responded to reduced irradiance by increasing leaf development at the expense of stem and seed production and biomass accumulation (Steckel et al. 2003). Patterson (1979) suggested that increased leaf area in proportion to total plant tissue could also constitute a response to excessive shade.

Photosynthetic efficiency and response to shade differs among weeds. Boyd and Murray (1982) reported silverleaf nightshade (*Solanum elaeagnifolium* Cav.) did not emerge under 92% shade and when seedlings were exposed to 92% shade, death occurred within a short time. Plants growing in full sunlight produced an average of approximately 2 leaves per day during a 10-day period; however, silverleaf nightshade under 63% shade averaged less than one leaf per day during the same time period. Established plants in full sunlight produced more than 7 times the dry matter compared with plants in 92% shade. It was concluded that a shade level between 63 to 97% would be necessary to prevent seed production.

Field bindweed (*Convolvulus arvensis* L.) plants established from seed were more vigorous than those established from rhizomes, and plants established from seed were less sensitive to shading (Dall'Armellina and Zimdahl 1988). These seedling of field bindweed were better adaptive under low light conditions. Common cocklebur (*Xanthium strumarium* L.), jimsonweed (*Datura stramonium* L.), velvetleaf (*Abutilon theophrasti* Medik.), and soybean, exposed to reduced irradiance resulted in decreased leaf thickness, increased chlorophyll content, and higher photosynthetic rate per unit leaf volume (Regnier et al. 1988). Godara et al. (2012) reported that Texasweed [*Caperonia palustris* (L.) St. Hil.] mitigated the adverse effect of shade by increasing SLA and percentage of leaf biomass. The adverse effects of shade can be overcome by increased plant height and shoot/root partitioning (Caton et al. 1997).

Most shade studies have been conducted with plants grown under constant shade levels for the duration of the experiment (Bello et al. 1995; Boyd and Murray 1982; Jha et al. 2008; Jones and Griffin 2010; Keeley and Thullen 1978; Knake 1972; Regnier et al. 1988; Santos et al. 1997; Steckel et al. 2003; Wiggans 1959). This methodology, although successful in determining weed response to shade, would not represent the conditions experienced under a crop canopy where photosynthetically active radiation (PAR) decreases with crop growth. In a comparison of the effect of shade establishment methods, gradual transfer and direct transfer of plants to a given shade level, Texasweed plants transferred from 0 to 30% shade, gradually transferred, produced greater biomass than did plants held continuously in 30% shade (Godara et al. 2012). Differences in plant biomass between the transfer methods were not observed at 56, 70, and 100 days after emergence.

Prickly sida has been observed in Louisiana to emerge in early March and to persist under a crop canopy. Following crop harvest, plants are able to initiate regrowth and to set seed. Little information is available concerning prickly sida response to shade. This research includes two studies. The first study evaluated prickly sida dry weight, plant height, node number, and seed production as affected by gradual increase in shade as would occur within a developing crop canopy. The intent was to simulate what would occur when prickly sida plants emerge in the crop early in the growing season and shade levels increase within the crop canopy as the season progresses. Plants exposed to a direct/constant shade level were also included for comparison with gradually transferred plants. The second shade study evaluated prickly sida seed production as affected by decreasing shade levels. The intent was to simulate what would occur for prickly sida plants that had persisted under the crop canopy for the entire growing season and with crop senescence and harvest, shade levels decrease within the crop canopy and weed regrowth occurs.

MATERIALS AND METHODS

Increasing Shade Level Study. A study evaluated prickly sida growth and reproduction as affected by both a constant shade regime and a gradual increase in shade exposure simulating growth with a crop. The study was conducted in 2011, 2012, and 2013 using potted plants under field conditions at the LSU AgCenter Northeast Research Station (NERS) near St. Joseph, LA. Black polyethylene 20.3 cm diameter pots with 7.6 liter volume capacity (International Greenhouse Co., Danville, IL 61832), were filled with a Sharkey clay soil (very fine, smectitic, thermic Chromic Epiaquerts) with a pH of 6.1 and 2.1% organic matter collected from a field site that had been fallowed for several years. In 2011, prickly sida seed from Azlin Seed Service (Azlin Seed Service, Leland, MS 38756) were used and in 2012 and 2013 prickly sida seed collected from fields at the NERS were used. Seed were planted in pots on June 16, 2011; June 8, 2012; and June 3, 2013. Prior to planting, all pots containing soil were watered to field capacity. After watering approximately 30 seed were placed in the center of the pot on top of the moist soil and covered with 0.5 cm of sand or Sharkey clay soil.

Shade levels consisted of 0, 30, 50, 70, and 90% and were achieved using 3.7-m by 1.8-m polypropylene fabric shade-cloth (International Greenhouse Co., Danville, IL 61832) draped over and secured a wooden A-frame structure measuring approximately 1.67-m tall by 3.7-m using plastic zip ties (Figures 3.1, a. and b.). Shade tent openings faced north and south with the covered sides oriented east and west. Shade intensities inside the tents, expressed as a percentage of the PAR outside the tents, were confirmed to be within 3% of the desired shade level using an AccuPAR linear PAR ceptometer (Decagon Devices, Inc., 950 NE Nelson Court, Pullman, WA 99163).

A randomized complete-block design consisting of four replications and three pots per replicate each year. Trial initiation occurred when prickly sida emerged on June 22, 2011; June 13, 2012; and June 6, 2013. Treatments included direct/constant shade regimes of 0 (no shade), 30, 50, 70, and 90% shade for the duration of the experiment. The remaining treatments included a gradual transfer where plants grown in 0, 30, 50, or 70% shade for two weeks and were then transferred to the next higher shade level. Prickly sida were thinned during the first two weeks of growth and four prickly sida plants remained in each pot prior at the first transfer.

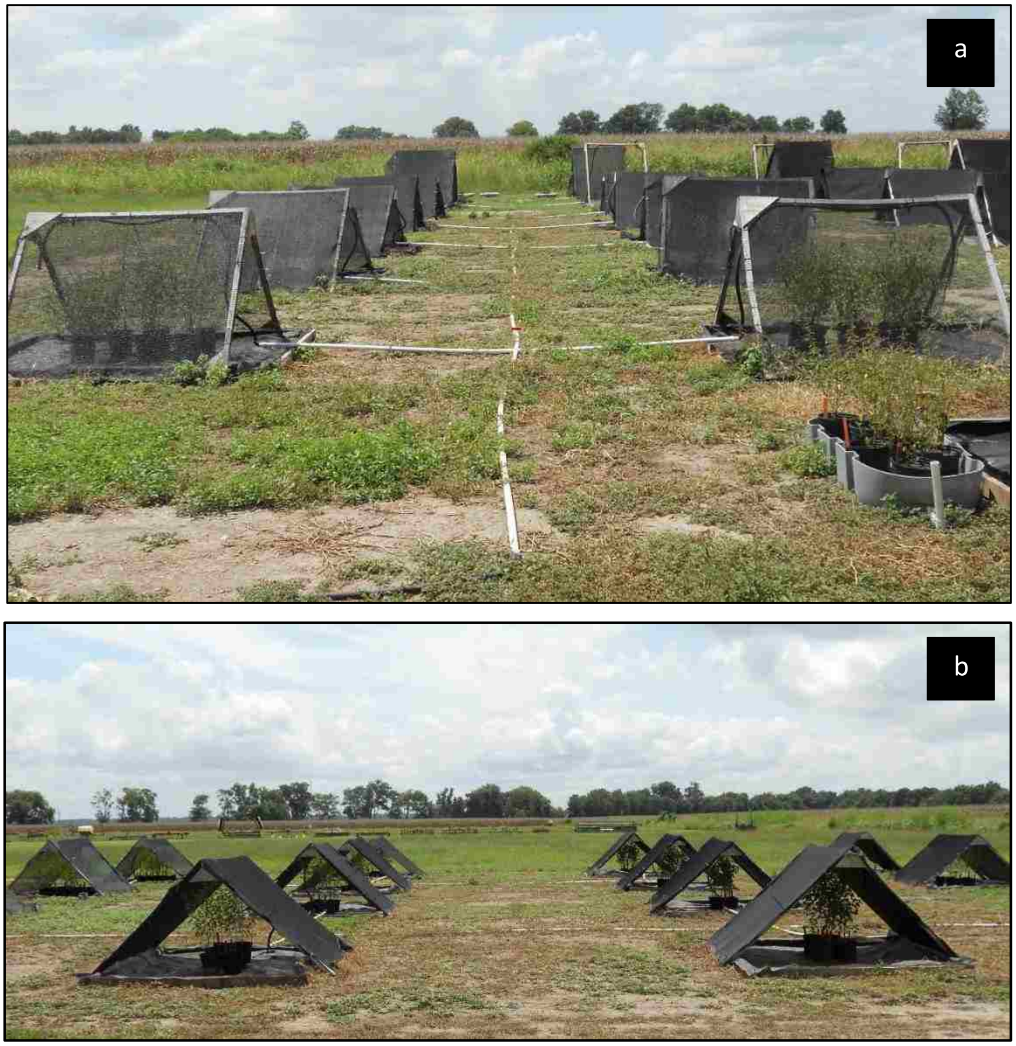


Figure 3.1. (a) A-frame shade structures showing watering system and wooden boxes used to catch seed; and (b) side view.

At the time of each transfer, plants that had reached their final shade level were retained as a group in that shade level, and others were transferred as a group to the next shade level until they reached their final shade level. At the time of each transfer the pots were randomized and spaced to avoid close contact with other plants and competition for light. Once transferred to the final shade level for the respective shade regime at 56 days, prickly sida plants were allowed to grow undisturbed until September 14, 2011, October 22, 2012, and September 23, 2013 when experiments were terminated. Throughout the duration of the experiment, pots were kept weed-free of other weeds by regular hand weeding.

A water supply system was built that allowed shade tents to be watered simultaneously (Figure 3.1, a.). Two brass ½ HH 30WSQ FullJet nozzles (Spraying Systems Co. Wheaton, IL 60187) were used to deliver water to each shade tent (Figure 3.2, b.). Water was supplied to the irrigation system from a pull-type water trailer equipped with a 5.5 horsepower motor (Figure 3.2, a.). Plants were watered as necessary to ensure that water was not a limiting factor to growth. This typically translated to watering the plants once a day. Because of the rapid growth and biomass accumulation early on for plants grown in full sun, pots for the 0% shade treatments were hand watered using either watering cans or water troughs measuring approximately 53 cm wide by 141 cm long by 22 cm deep (Figure 3.3, a.). Troughs held approximately 10 to 15 cm of water and plants/pots were sub-irrigated until the soil was visibly saturated.

To aid in seed collection, pots within each treatment were placed in a 2.4 m x 3.7 m x 0.1 m wooden box set under the A-frame watering structures (Figure 3.1, a. and b.). A water permeable weed suppressing fabric (Fabriscape Inc., Bedford Park, IL 60638) was attached to the bottom of the wooden boxes. The wooden boxes served to catch seed that may have fallen from the prickly sida plants. In 2012 and 2013, prickly sida mature seed capsules, a brown dry capsule with dried brown seed visible, were hand removed in the 0% constant shade treatment at regular intervals. For treatments 2 through 15 (Table 3.1) prickly sida plants in each treatment were hand harvested at the conclusion of the experiment and the remaining seed capsules were removed from the plant and threshed. Also, the wooden boxes were vacuumed out separately and the entire contents of the vacuum emptied into a cloth bag measuring 34.29 cm wide by 63.5 cm long.

Figure 3.2. (a) Water trailer used for water supply; (b) two brass ½ HH 30WSQ FullJet nozzles; and (c) prickly sida pots shortly after watering.

Figure 3.3. Water troughs measuring approximately 53 cm wide by 141 cm long by 22 cm deep and contained approximately 10 to 15 cm of water.

Table 3.1. Starting shade level, days after transfer of prickly sida to each successive shade level, and final shade level for the 15 treatments evaluated in the increasing shade study at the Northeast Research Station, St. Joseph, LA.[1]

Shade treatment[2]	Starting shade level (%)	Days after study initiation				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

[1]Prickly sida seed were planted in pots on June 16, 2011; June 8, 2012; and June 3, 2013. Shade treatments were initiated 3 to 6 days later when prickly sida emerged. Termination of the experiments occurred on September 14, 2011; October 22, 2012; and September 23, 2013.

[2]For treatments 1, 6, 10, and 15, prickly sida plants were exposed to starting shade levels of 0, 30, 50, 70, and 90%, respectively, and these levels remained constant throughout the study. For the remaining treatments, prickly sida plants were transferred at 14 day intervals to the next higher shade level and from that point on plants were either transferred to the next higher shade level or remained at their current shade level for the duration of the study. The final shade level for each treatment is provided.

To account for all of the seed produced by plants, each pot was removed from the shade tents and the upper most top soil (soil that was loose) was separated from any seed which had fallen into the pots using a modified version of a water-spray system employed by Kovach et al. (1988). The seed extractor consisted of a base frame, an electric Dayton parallel shaft high torque AC gear motor with a 30 rpm rating (Grainger Inc., Baton Rouge, LA 70817), a plate metal shield where the motor attaches, a rotating cradle that holds an aluminum funnel to which a removable stainless steel sieve (Solutions Direct, Riverside, CA 92517) (20.3 cm diameter and no. 20 mesh size) is attached, and a water nozzle spraying system (Figure 3.4, a.- d.). A U.S. no. 20 mesh size (0.841 mm) was chosen because prickly sida seed range between 1.0 to 3.0 mm in length (Bryson and DeFelice, 2009).

The procedure for seed extraction was as follows: the entire soil volume from all pots in each shade regime/treatment was emptied into a 5 gallon bucket, water was added to the bucket until the soil was completely submersed, the soil/water was then stirred using an 18 volt 1.27 cm drive cordless power drill with a dry wall mixer attachment until water and soil were mixed thoroughly, the suspension was allowed to settle and remixed three more times while cleaning the mixer over the bucket each time used. The water-spray seed extractor was engaged and the slurry poured into the soil funnel, the water pressure and nozzle attachment was adjusted as needed to ensure a thorough wash. Once the soil had been separated from the seed, the funnel and sieve were removed from the cradle. Seeds and other material were removed from the sieve and air dried. Air drying allowed facilitation of prickly sida seed counting.

Prickly sida seed number was determined by hand counting all the seed collected for a treatment sample or through estimation based on seed number, weight, and volume. Seed estimation was determined from 5 samples of 50 seed weight, and by hand counting 3 to 10, 2.5

ml sub-samples of seed from each treatment and measuring total treatment volume using a graduated cylinder. The method used (hand counting or estimation) was determined based on the number of seed and the amount of debris remaining after seed cleaning.

Figure 3.4 (a,b) Water-spray system used to extract prickly sida seed from soil; (c) aluminum pipe and sieve; and (d) drill and dry wall mixer used in preparing soil slurry.

Node number, plant height, and aboveground biomass data were measured for individual plants in each treatment at termination of the experiments. Plant height was measured from the cotyledon node to the top of the plant. Dry weight was determined after plants were air dried in a hot greenhouse. Dry weight per plant, plant height, and node number per plant data were subjected to ANOVA using Standard Least Squares method in Fit Model functionality in JMP®

software (JMP 2015). A mixed model with treatment (shade regime) as fixed effects was used. Years and replications within a year were considered random effects. Type III tests were used to test significance of fixed effects. LSMEANS were used for treatment comparison and Fisher's protected LSD was used for mean separation. Data for seed per plant collected in 2012 and 2013 were subjected to square root transformation to homogenize the variance and were analyzed by ANOVA and mean comparison as described above. Data were retransformed for presentation.

Decreasing Shade Level Study. This study evaluated prickly sida seed production potential as influenced by a gradual decrease in shade level across the growing season. Selection of shade levels and the number of days exposed to each was to simulate prickly sida emergence under a heavy crop canopy (90% shade) with shade levels decreasing as the crop senesced. Movement of plants to full sun would represent crop canopy removal after harvest. Experiments were conducted in 2012 and 2013 at the LSU AgCenter NERS using potted plants under field conditions. Black polyethylene 28.3 cm diameter pots, 9.5 liter volume capacity (International Greenhouse Co., Danville, IL 61832) were filled with a Sharkey clay. On June 8, 2012 and June 3, 2013, approximately 30 prickly sida seed collected from fields at the NERS were placed in the center of each pot on top of moist soil and covered with 0.5 cm of sand or Sharkey clay soil.

Shade levels consisted of 0, 50, 70, and 90% and were achieved using shade cloth as described previously. A completely randomized design with 15 replications (15 pots) was used. Plants were placed under A-frame tent structures and were watered as described for the first shade study. On June 11, 2012 and June 4, 2012 prior to prickly sida emergence, pots were moved to the 90% shade tents and the experiment was initiated. Two treatments were included in each experiment and shade regimes represented a gradual transfer with plants starting at 90% shade and ending in 0% shade (full sun). For treatment 1, 15 pots were placed under 90% shade for 30 days. When prickly sida reached four leaf, plants were thinned to one per pot and pots were kept free of other weeds by regular hand weeding. At the end of the 30-day period for treatment 1, 10 plants of the original 15 for each treatment were selected based on uniformity in height and were transferred to the 70% shade enclosure for 30 days and then moved to the 50% enclosure for 15 days. At the end of the 15-day period, plants were placed in full sun until the experiment was terminated.

For treatment 2, pots were placed under 90% shade, as was also the case for treatment 1, and thinning and weed removal was as described for treatment 1. Unlike treatment 1, however, pots for treatment 2 remained under 90% shade for 60 days. The 30 additional days under 90% shade for treatment 2 was included to represent prickly sida plants that may emerge early in the growing season and experience a longer initial shade period. At the end of the 60-day period for treatment 2, 10 plants selected for uniformity and were transferred to the 70% shade enclosure for 30 days, to the 50% enclosure for 15 days, and to full sun until the experiment was terminated. Specific planting dates and duration of plant exposure to shade levels for the treatments each year are provided in Table 3.2.

When plants were observed with mature seed capsules, capsules were removed and threshed by hand. Seed production was initiated on August 28, 2012, 78 days after 90% shade initiation and on August 9, 2013, 66 days after 90% shade initiation. As described for the first shade study, prickly sida seed that naturally shed from plants due to rain or windy conditions were vacuumed from each box on the day seed capsules were removed from plants.

Based on the number of plants and the level of seed production that occurred at each seed collection date, total seed number for the 10 plants was either hand counted or estimated as described previously. Seed from the 10 plants in each treatment were composited.

Table 3.2. Prickly sida planting date and duration of plant exposure to 90, 70, 50, and 0% (full sun) shade levels for two treatments evaluated in 2012 and 2013 in the decreasing shade level study at the Northeast Research Station, St. Joseph, LA.

		Shade level			
Treatment	Planting date	90% shade	70% shade	50% shade	0% shade (full sun)
1	June 8, 2012	June 11 - July 10 (30 days)	July 10 - August 9 (30 days)	August 9 - 24 (15 days)	August 24 - November 10 (79 days)
2	June 8, 2012	June 11 - August 10 (60 days)	August 10 - September 9 (30 days)	September 9 - 24 (15 days)	September 24 - November 10 (48 days)
1	June 3, 2013	June 4 - July 15 (30 days)	July 15 - August 6 (30 days)	August 6 - 21 (15 days)	August 21 - October 2 (62 days)
2	June 3, 2013	June 4 - August 6 (60 days)	August 6 - September 6 (30 days)	September 6 - 20 (15 days)	September 20 - October 2 (13 days)

Termination of the experiments occurred when seed set was completed, which corresponded to November 10, 2012 and October 2, 2013. Data are presented for each year as seed production per plant at each seed collection date and as cumulative seed production per plant across the growing season. Because seed for each of the 10 plants per treatment for each year were consolidated, statistical analysis for the two treatments could not be conducted.

RESULTS AND DISCUSSION

Increasing Shade Level Study. Prickly sida dry weight, plant height, node number per plant, and seed per plant data for the treatments are presented in Table 3.3. Treatments are arranged based on the final shade levels of 0, 30, 50, 70, and 90% to allow for ease in comparison of direct/constant shade and gradual transfer to the final/ending shade levels. Prickly sida dry weight was 48.4 g $plant^{-1}$ for the 30% constant shade regime (Table 3.3) and equivalent to only the no shade for 14 days followed by 30% shade for the remainder of the study which produced 44.1 g $plant^{-1}$ dry weight. For these two treatments with 30% as the final shade level dry weight per plant averaged 94% greater than for the no shade/full sun treatment. For the other treatments with final shade levels of 50, 70, or 90%, dry weight was equivalent to the full sun treatment. Godara et al (2012) reported Texasweed plants gradually transferred to 30% shade produced greater biomass than plants maintained continuously at 30% shade. As time progressed the differences observed between gradual transfer and constant shade treatments disappeared and differences were not observed at 56, 70, and 100 DAE. In the present study, for all of the shade treatments with an ending shade level of 90%, dry weight averaged 65 and 52% less compared with shade treatments ending in 30 and 50% shade, respectively. The fact that dry weight for 30% final shade treatments was greater than no shade and dry weight for the 50, 70, and 90% final shade treatments was equivalent to no shade was not expected. Godara et al. (2012).

Table 3.3. Treatment shade regimes and resulting effects on prickly sida dry weight per plant, plant height, node number per plant, and seed production of prickly sida in the increasing shade level study at the Northeast Research Station, St. Joseph, LA.

Shade regime (%)[1]	Dry weight (g $plant^{-1}$)	Plant height (cm)	Nodes per plant (no.)	Seed per plant (no.)
0-0-0-0-0	23.9 cdefg[2]	71.2 e[2]	35 a[2]	1851 abc[3]
30-30-30-30-30	48.4 a	77.4 de	34 ab	2685 ab
0-30-30-30-30	44.1 ab	77.3 de	34 abc	3008 a
50-50-50-50-50	35.2 bc	88.3 abc	34 abc	1665 a-d
0-30-50-50-50	30.0 cde	78.1 d	33 abc	1264 bcd
30-50-50-50-50	34.6 bcd	90.8 ab	35 a	1622 a-d
70-70-70-70-70	21.8 efg	88.3 abc	32 bcd	1142 bcd
0-30-50-70-70	26.8 cdef	86.8 bc	35 a	1177 bcd
30-50-70-70-70	22.7 defg	87.5 abc	35 a	1418 a-d
50-70-70-70-70	29.6 cde	94.2 a	34 abc	904 cd
90-90-90-90-90	17.0 fg	82.2 cd	29 e	604 cd
0-30-50-70-90	14.4 g	88.0 abc	34 abc	780 cd
30-50-70-90-90	17.3 fg	90.6 ab	33 abc	558 d
50-70-90-90-90	16.4 fg	87.5 abc	30 de	684 cd
70-90-90-90-90	14.7 fg	87.4 abc	31 cde	595 cd

[1]See Table 3.1 for treatment descriptions and study information.

[2]Means within each column followed by a common letter are not significantly different based on LSD at P = 0.05.

[3]Data represent 2012 and 2013. Means followed by a common letter are not significantly different based on LSD at P = 0.10.reported 13, 20, 36, and 58% reduction in dry matter for final shade levels of 30, 50, 70, and 90%, respectively, compared with 0% shade.

Bello et al. (1995) reported a decrease in velvetleaf (*Abutilon theophrasti* Medik.) dry weight as constant shade level increased from 0 to 76%, and Steckel et al. (2003) observed biomass reductions in common waterhemp as shade levels increased from 40 to 99%.

Prickly sida height for treatments with a final shade level of 30% and did not differ, averaging 77.5 cm and were the only treatments where plant height was equivalent to no shade (Table 3.3). Plant height for treatments with a final shade level of 30% in most cases was less than for treatments ending in 50, 70, or 90% shade. For treatments with a 50% final shade level, plant height for gradual transfer treatments was either equal to or less than that for the 50% constant shade. In contrast, for the treatments with 70 and 90% final shade level, plant height for gradual transfer was either equal to or greater than constant shade. In contrast to other research, velvetleaf height was reduced by 70% shade but was not reduced by 30% shade (Bello et al. 1995) and common waterhemp final plant height was equivalent for plants growing in 0, 40, and 68% shade (Steckel et al. 2003).

Prickly sida node number was equivalent for treatments with 30 and 50% final shade levels (33 to 35 nodes plant^{-1}) (Table 3.3). For plants with 70% final shade, node number was generally greater for gradual transfer compared with constant shade. Node number for plants ending in 90% shade with gradual transfer was either greater than or equal to that for 90% constant shade. Prickly sida node number for the no shade treatment (35 nodes per plant) was equivalent to that for the 30 and 50% constant shade treatments but was greater than that for the 70 and 90% constant shade treatments.

For each of the constant shade regimes of 30, 50, 70, and 90%, seed production per plant was no greater (P = 0.10) than when gradual transfer occurred to the final shade level of 30, 50, 70, or 90% (Table 3.3). For the no shade treatment seed production per plant was 1851 and in most cases was equivalent to the other treatments. Seed production was equivalent for 50, 70, and 90% constant shade treatments. For 30% constant shade, seed production was 4.5 times greater compared with 90% constant shade. This large increase in seed production was accompanied by 2.8 times greater dry weight per plant for 30% constant shade compared with 90% and 5 more nodes per plant for 30% constant shade compared with 90% constant shade. Other researchers have reported fruit/seed production decreases with increasing shade levels (Bello et al. 1995; Boyd and Murray 1982; Keeley and Thullen 1978; Santos et al. 1997; Steckel et al. 2003). Godara et al. (2012) reported that Texasweed plants in constant full sunlight produced the greatest capsule number per plant, but capsule production was equal for plants ending in 30, 50, and 70% shade.

Results show that a 30% shade environment (30% constant shade and 30% shade following 14 days of no shade) would favor both prickly sida biomass accumulation and seed production. The ability of prickly sida to readily tolerate 30% shade would account for its competitiveness with crops early in the growing season and its ability to recover from early season herbicide injury. Prickly sida was also able to reproduce when exposed to 90% shade season long. For silverleaf nightshade, Boyd and Murray (1982) concluded that seed production could be prevented by shade levels of 63 to 97%. The fact that prickly sida does not require light for germination (Baskin and Baskin 1984; Smith et al.1992) suggests that plants would be able to emerge later in the growing season and persist under a heavy crop canopy until crop harvest.

Decreasing Shade Level Study. For treatment 1, plants were grown for 30 days in 90% shade, 30 days in 70% shade, 15 days in 50% shade, and in no shade (full sun) until the experiment was terminated (Table 3.2). For treatment 2, prickly sida plants were grown for 60 days in 90% shade (30 days longer than for treatment 1), 30 days in 70% shade, 15 days in 50% shade, and in no shade (full sun) until the experiment was terminated.

In 2012, seed production was first observed 78 days after 90% shade initiation for treatment 1 and 90 days after shade initiation for treatment 2 (Table 3.4). Seed production in 2012 for treatment 1 totaled 15 in August; 3,680 in September (90 to 103 days after 90% shade initiation); 1,598 in October (118 and 133 days after shade initiation); and 23 in November (152 days after shade initiation) and plants were under full sun at each of the seed collection dates. For treatment 2 in 2012, seed production was none in August; 2,718 in September; 2,100 in October;

Table 3.4. Influence of shade level on prickly sida seed production per plant from August through experiment termination in 2012 and 2013 in the decreasing shade level study, at the Northeast Research Station, St. Joseph, LA.

		Treatment 1[1]		Treatment 2[1]	
Data collection date	Days after 90% shade initiation[1]	Shade level at data collection (%)	Seed production per plant	Shade level at data collection (%)	Seed production per plant
2012					
August 28	78	0	15	70	0
September 9	90	0	283	70	99
September 16	97	0	1880	50	471
September 22	103	0	1517	50	2148
October 7	118	0	992	0	1763
October 22	133	0	606	0	337
November 10	152	0	23	0	30
2013					
August 9	66	50	5	70	0
August 16	73	50	5	70	0
August 23	80	0	245	70	2
August 30	87	0	320	70	11
September 8	96	0	1315	50	91
September 16	104	0	2295	50	1275
September 19	107	0	1428	50	1702
September 25	113	0	1533	0	1628
September 30	118	0	984	0	935
October 2	120	0	35	0	31

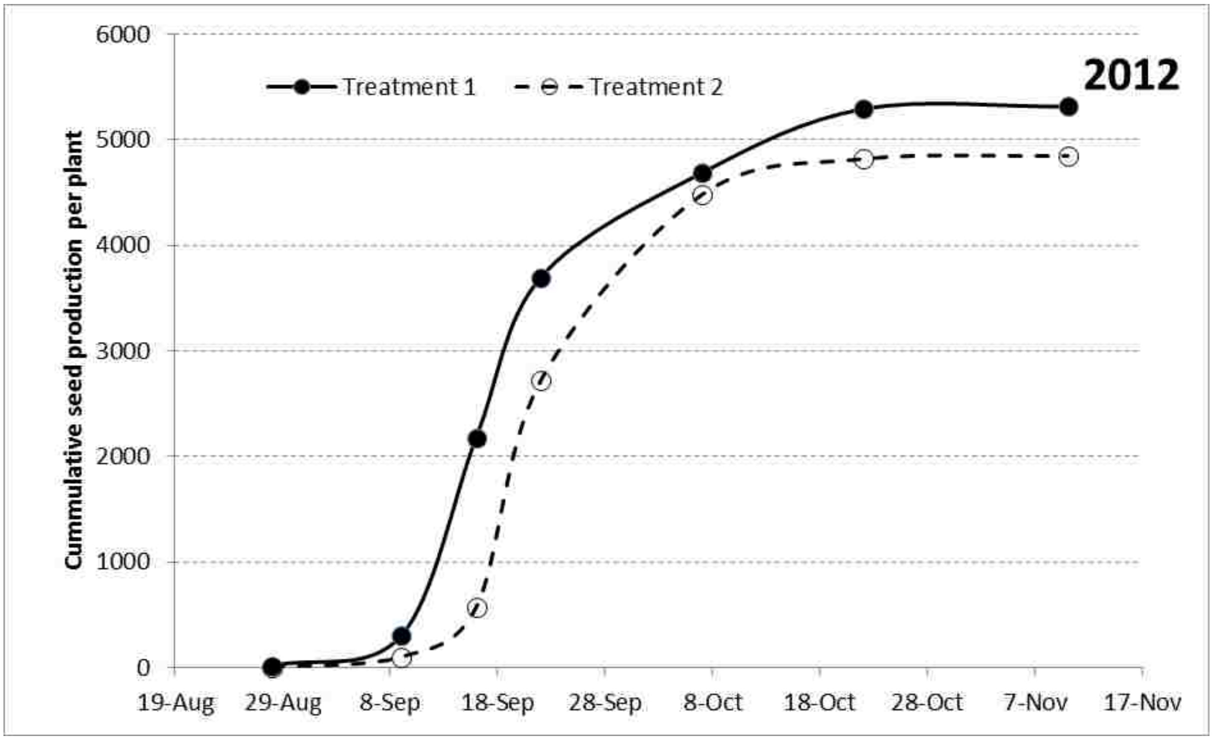
[1]For treatment 1, plants were grown for 30 days in 90% shade, 30 days in 70% shade, 15 days in 50% shade, and 0% shade (no shade/full sun) until experiment termination. For treatment 2, plants were grown for 60 days in 90% shade, 30 days in 70% shade, 15 days in 50% shade, and 0% shade until experiment termination (See Table 3.1).

and 30 in November. Seed production occurred when plants were under 70% shade in August and early September and under 50% shade in mid- and late-September. Plants were under full sun when data were collected in October and November.

In 2013, seed production was first observed 66 days after 90% shade initiation for treatment1 and 80 days after shade initiation for treatment 2 (Table 3.4). For treatment 1 in 2013, seed production was 10 in early August (66 and 73 days after 90% shade initiation); 565 in late August (80 and 87 days after shade initiation); 7,555 in September (96 to 118 days after shade initiation); and 35 in October (120 days after shade initiation). Seed production occurred when plants were under 50% shade in early August and full sun at each of the remaining seed collection dates. For treatment 2 in 2013, seed production was none in early August and 13 in late August; 5,631 in September; and 31 in October. Seed production occurred when plants were under 70% shade in August, 50% shade in September, and full sun in late September and October.

In both years peak seed production occurred during September for both treatments. Even though data could not be analyzed statistically some interesting findings were observed. Total seed production both years during September was around 35% greater for treatment 1 compared with treatment 2 (Table 3.4). Additionally, total seed production for both treatments in September was 2.1 times greater in 2013 compared with 2012.

Cumulative seed production per plant across the growing season clearly shows the consistent greater seed production for treatment 1 as well as the greater seed production for 2013 (Figure 3.5). Data also show the ability of plants in both treatments to reproduce as shade levels decreased (Table 3.4). On September 9 of 2012, 90 days after 90% shade initiation, cumulative prickly sida seed production was 3.0 times greater for treatment 1 compared with treatment 2. In contrast, on August 30, 2013, 87 days after 90% shade initiation, cumulative prickly sida seed production was 44 times greater for treatment 1 compared with treatment 2. On both September 9, 2012 and August 30, 2013, prickly sida in treatment 1 was growing in full sun whereas for treatment 2, plants were under 70% shade, which can explain the large difference in seed production observed.



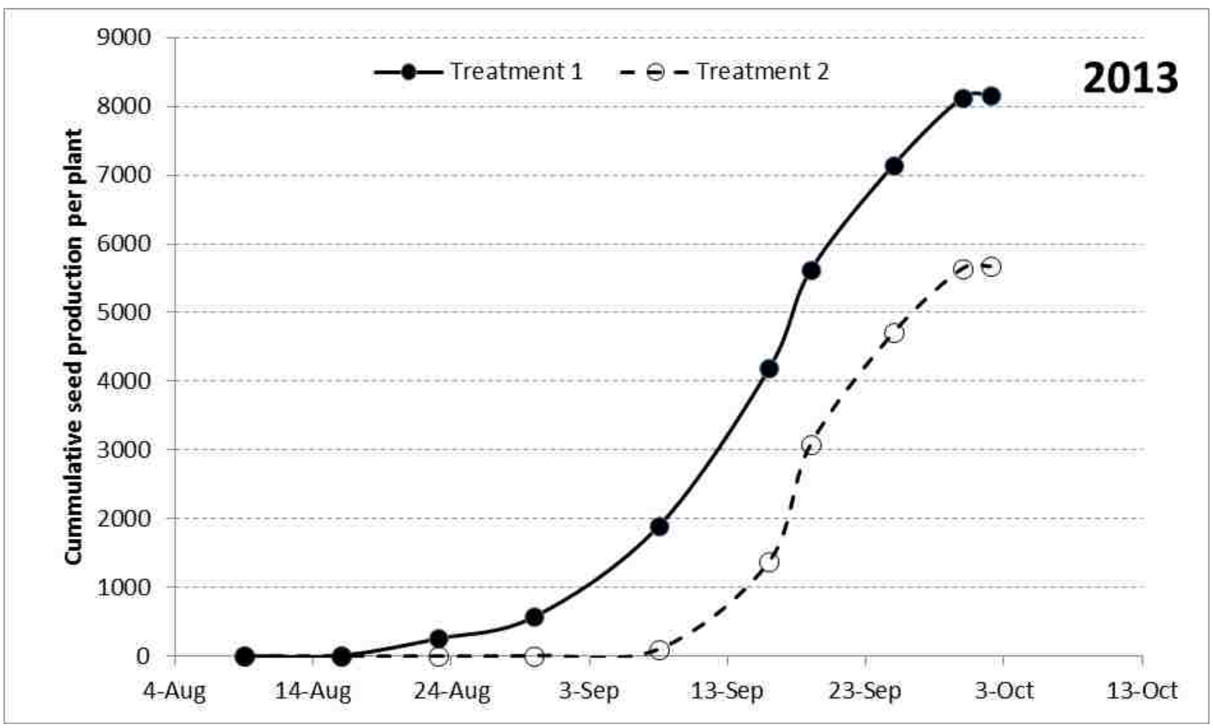


Figure 3.5. Cumulative prickly sida seed production following exposure to 90, 70, 50, and 0% (full sun) shade in 2012 and 2013 in the decreasing shade level study. Treatment 1 = 90% shade for 30 days, 70% shade for 30 days, 50% shade for 15 days, and 0% shade until experiment termination. Treatment 2 = 90% shade for 60 days, 70% shade for 30 days, 50% shade for 15 days, and 0% shade until experiment termination. (See Tables 3.3 and 3.4).

On September 22 in 2012, 103 days after 90% shade initiation, and on September 16 in 2013, 104 days after 90% shade initiation, prickly sida plants were under full sun for treatment 1 and under 50% shade for treatment 2 (Figure 3.5). Cumulative seed production was 1.4 times greater for treatment 1 in 2012 and 3.0 times greater for treatment 1 in 2013. At 118 days after 90% shade initiation cumulative seed production on October 7, 2012 was only 5% greater for treatment 1 compared with treatment 2, but seed production on September 30, 2013 was 44% greater for treatment 1 compared with treatment 2. Comparing years, total cumulative seed production for treatment 1 was 10% greater than treatment 2 in 2012 and 44% greater in 2013. In 2012, 83% of total seed production occurred between 97 and 118 days after 90% shade initiation for treatment 1 and 90% of total seed production occurred during the same period for treatment 2. In 2013, 80 and 83% of the total seed production occurred for the treatments between 96 and 113 days after 90% shade initiation.

This study was conducted to evaluate potential seed production when prickly sida plants emerge under an actively growing crop and with crop senescence and dry down shade levels decrease. Although for treatment 2 plant exposure to 90% shade was 30 days longer than for treatment 2, prickly sida cumulative seed production was still significant for the two years and totaled in excess of 4800 seed per plant.

Results from the shade studies show that prickly sida is adapted to heavy shade environments and has the potential to produce a significant amount of seed when exposed to both increasing and decreasing shade levels as the growing season progresses. Under a 30% shade environment, an optimal environment for prickly sida dry matter accumulation and seed production based on this research, around 3,000 prickly sida seed were produced per plant. Although only around 550 seed plant^{-1} were produced when shade levels gradually increased from 30 to 90%, this level of fecundity would be considered significant. With exposure to 90% shade in the early season followed by a gradual decrease in shade to full sun, total seed production was as high as around 8,100 seed $plant^{-1}$. Prickly sida is especially adept at producing seed later in the growing season after crop senescence and harvest.

In recent years in Louisiana, growers and consultants have reported increased problems with control of prickly sida in soybean. From a long-term management approach it would be important to discourage weed seed production and replenishment of the soil seed bank. The innate ability of prickly sida to emerge and to persist under a heavy shade environment suggests that the crop itself would provide little competition for prickly sida. With corn harvest beginning in July in Louisiana and soybean harvest in August there would be ample time for established prickly sida plants to regrow or for new plants to set seed. This research shows that prickly sida seed production can occur as early as 78 days following 90% shade exposure. An integrated weed management strategy that includes weed control measures both early in the growing season and after crop harvest would be warranted to prevent substantial prickly sida seed production and replenishment of the soil seedbank.

LITERATURE CITED

Baskin JM, Baskin CC (1984) Environmental conditions required for germination of prickly sida (*Sida spinosa*). Weed Sci 32:786-791.

Bazzaz FA, Carlson RW (1982) Photosynthetic acclimation to variability in the light environment of early and late successional plants. *Oecologia* 54:313-316.

Bello IA, Owen MDK, Hatterman-Valenti HM (1995) Effect of shade on velvetleaf (*Abutilon theophrasti*) growth, seed production, and dormancy. Weed Technol 9:452-455.

Benech-Arnold RL, Ghersa CM, SaÂnchez RA, GarcõÂa Fernandez A (1988). The role of fluctuating temperatures in the germination and establishment of *S. halepense* (L.) Pers. Regulation of germination under leaf canopies. Funct Ecol 2:311-318.

Boyd JW, Murray DS (1982) Effects of shade on silverleaf nightshade (*Solanum elaeagnifolium*). Weed Sci 30:264-269.

Bryson CT, DeFelice MS (2009) Weeds of the South. University of Georgia Press, Athens, GA. Pp. 468.

Caton BP, Foin TC, Hill JE (1997) Phenotypic plasticity of Ammannia spp. in competition with rice. Weed Res 37:33-38.

Dall'Armellina AA, Zimdahl RL (1988) Effect of light on growth and development of field bindweed (*Convolvulus arvensis*) and Russian knapweed (*Centaurea repens*). Weed Sci 36:779-783.

Godara RK, Williams BJ, Geaghan JP (2012) Effect of shade on Texasweed (*Caperonia palustris*) emergence, growth, and reproduction. Weed Sci 60:593-599.

Holt JS (1995) Plant responses to light: A potential tool for weed management. Weed Sci 43:474-482.

Jha P, Norsworthy JK (2009) Soybean canopy and tillage effects on emergence of palmer amaranth (*Amaranthus palmeri*) from a natural seed bank. Weed Sci. 57:644–651.

Jha P, Norsworthy JK, Riley MB, Bielenberg DG, Bridges Jr. W (2008) Acclimation of Palmer amaranth (*Amaranthus palmeri*) to shading. Weed Sci 56:729-734.

JMP® 2015, Version 12.0.0. SAS Institute Inc., Cary, NC, 1989-2015.

Jones CA, Griffin JL (2010) Red morningglory (*Ipomoea coccinea*) response to tillage and shade. J. Am. Soc. Sugarcane Technol. 30:11–20.

Jordan DL, York AC, Griffin JL, Clay PA, Vidrine PR, Reynolds DB (1997) Influence of application variables on efficacy of glyphosate. Weed Technol 11:354-362.

Keeley PE, Thullen RJ (1978) Light requirements of yellow nutsedge (*Cyperus esculentus*) and light interception by crops. Weed Sci 26:10-16.

Knake EL (1972) Effect of shade on giant foxtail. Weed Sci 20:588-592

Kovach DA, Thill DC, Young FL (1988) A water-spray system for removing weeds from the soil. Weed Technol 2:388-341.

Norsworthy JK (2004) Soybean canopy formation effects on pitted morningglory (*Ipomoea lacunosa*), common cocklebur (*Xanthium strumarium*), and sicklepod (*Senna obtusifolia*) emergence. Weed Sci 52:954-960.

Patterson DT (1979) The effects of shading on the growth and photosynthetic capacity of itchgrass (*Rottboellia exaltata*). Weed Sci 47:549-553.

Patterson DT (1980) Shading effects on growth and partitioning of plant biomass in cogongrass (*Imperata cylindrical*) from shaded and exposed habitats. Weed Sci 28:735-740.

Rankins Jr. A, Boyd Jr. JD, Mask DB, Barnett JW, Gerard PD (2005) Survey of soybean weeds in Mississippi. Weed Technol 19:492-498.

Regnier EE, Salvucci ME, Stoller EW (1988). Photosynthesis and growth responses to irradiance in soybean (*Glycine max*) and three broadleaf weeds. Weed Sci 36:487-496.

Santos BM, Morales-Payan JP, Stall WM, Bewick TA, Shilling DG (1997) Effects of shading on the growth of yellow nutsedge (*Cyperus* spp.). Weed Sci 45:670-673.

Smith CA, Shaw DR, Newsom LJ (1992) Arrowleaf sida (*Sida rhombifolia*) and prickly sida (*Sida spinosa*): germination and emergence. Weed Res 32: 103-109.

Steckel LE, Sprague CL, Hager AG, Simmons FW, Bollero GA (2003) Effects of shading on common waterhemp (*Amaranthus rudis*) growth and development. Weed Sci 51:889-903.

Webster TM, Coble HD (1997) Changes in weed species composition of the Southern United States: 1974 to 1995. Weed Technol 11:308-317.

Webster TM, Nichols RL (2012) Changes in the prevalence of weed species in the major agronomic crops of the Southern United States: 1994/1995 to 2008/2009. Weed Sci 60:145-157.

Wiggans SC (1959) Response of oat plants to various percentages of continuous shade. Bot Gaz 212:55–60.

CHAPTER 4
PREPLANT AND IN-CROP HERBICIDE PROGRAMS FOR PRICKLY SIDA (SIDA SPINOSA) CONTROL IN SOYBEAN

INTRODUCTION

Weed competition in crops is dependent on row spacing (Knezevic et al. 2003), tillage system (Halford et al. 2001), weed species (Bensch et al. 2003; Cowan et al. 1998), and weed density (Bensch et al. 2003; Thurlow and Buchanan 1972). The effect of weed competition on yield can vary across locations and years (Halford et al. 2001; Van Acker et al. 1993). In soybeans, the critical time for weed removal can range from emergence to R3, but most research shows that weed removal within 2 to 4 weeks after crop emergence (WAE) can prevent yield loss (Ellis and Griffin 2002; Eyherabide and Cendoya 2002; Hager et al. 2002; Halford et al. 2001; Thurlow and Buchanan 1972; Van Acker et al. 1993; Vangessel et al. 2000). The critical weed free period is from V1 to R3 or approximately 4 to 8 WAE (Eaton et al. 1976; Eyherabide and Cendoya 2002; Halford et al. 2001; Van Acker 1993; Wilson and Cole 1966).

Prickly sida (*Sida spinosa* L.) is widely distributed in the southern U.S. and is a troublesome broadleaf weed in cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), peanut (*Arachis hypogaea* L.), and soybean [*Glycine max* (L.) Merr.] (Webster and Coble 1997; Webster and Nichols 2012). Prickly sida densities of 50 to 120 plants m^{-2} are capable of reducing soybean yield 9 to 14% (Jeffery et al. 1976). A survey conducted in Mississippi showed prickly sida present in 40% of sampled fields, making it the most prevalent weed (Rankins et al. 2005). Prickly sida was reported as the most troublesome weed of cotton in 1974 and second most in 1983 (Webster and Coble 1997). By 2008 and 2009 prickly sida ranked as the 19th most troublesome weed in corn and soybean and 14th in cotton (Webster and Nichols 2012).

Weed control in soybean changed dramatically in the mid 1990's with the introduction and adoption of glyphosate-resistant (GR) soybean (Rankins et al. 2005). As a result tillage practices shifted toward reduced tillage practices and increased reliance on glyphosate both preplant and in-crop (Givens et al. 2009a; Givens et al. 2009b). These changes resulted in decreased use of residual herbicides and over dependence on postemergence (POST) herbicides (Carpenter and Gianessi 1999). Long-term use of glyphosate selected for glyphosate-resistant weeds (Heap 2016). Although prickly sida has not been documented as resistant to glyphosate it has become more prevalent in mid-South cropping systems.

Effective control of prickly sida has been achieved in soybean using preemergence (PRE) herbicides (Askew et al. 1999; Barnes and Oliver 2004; Burke et al. 2002; Culpepper et al. 2000; Green et al. 1988; Jeffery et al. 1976; Reddy 2000; Vidrine et al. 1996) or using a POST herbicide following a PRE treatment (Askew et al. 1999; Jeffery et al. 1976; Vidrine et al. 1996). Prickly sida control with POST herbicides has been variable. Factors such as plant size at application (Jordan et al. 1997; Norris et al. 2001; Vidrine et al. 1993), environmental conditions prior to and after herbicide application (Vidrine et al. 1993), and growing conditions later in the season (Ellis and Griffin 2003) can all influence weed control. Vidrine et al. (1993) concluded that for adequate POST control of prickly sida, acifluorfen plus bentazon should be applied before weeds reach 5 cm in height or approximately the 4 leaf stage. Control was enhanced when rainfall was received one week before and after treatment. Glufosinate at 290 to 400 g ha^{-1} controlled 3- to 4-leaf prickly sida 96 to 98% 8 weeks after application and control was 84 to 88% when application was made at 10- to 14-leaf (Culpepper et al. 2000). Glyphosate applied at 1- to 3-leaf controlled prickly sida at least 90% and control was more consistent than when applied at 4- to 6-leaf (Ellis and Griffin 2003).

A program approach for prickly sida control using herbicides with PRE and POST activity would be expected to provide consistent season long control. Herbicide programs that included residual herbicides applied prior to or at planting followed by single or multiple POST herbicide applications controlled prickly sida 80 to 98% with many of the programs providing greater than 90% control (Barnes and Oliver 2000; Beyers et al. 2002; Culpepper et al. 2000; Ellis and Griffin 2002; Payne and Oliver 2000).

A common practice in the Mid-South is to “burndown” fields prior to planting with herbicides applied preplant in February/March to control winter weeds and to provide residual weed control until planting. Growers would then have the option if seedbeds are weed-free to omit a herbicide at planting and to follow with POST herbicides as needed. Assuming weeds are present at planting a burndown herbicide could be used and growers could opt as to whether or not a residual herbicide is added. The addition of residual herbicides in a weed control program would also be of value in the management of herbicide-resistant weeds (Heap 2016). Prickly sida emergence in northeastern Louisiana can occur as early as the first week of March. Producers have relied primarily on multiple glyphosate applications for weed management and prickly sida has become more prevalent in soybean fields. When residual herbicide is not used at planting, environmental conditions and time constraints may result in weeds too large for glyphosate to be effective. Prickly sida has been observed to germinate across the growing season, persist under a crop canopy, and regrow and produce seed after crop harvest. This suggests that a programs approach with residual herbicides applied burndown preplant and at-planting followed by POST herbicides in-crop may be needed to maximize control. This research addresses the value of residual herbicides applied preplant, at-planting, and POST for control of prickly sida in glyphosate-resistant soybean and also the effect of prickly sida competition from lack of weed control on soybean growth and yield.

MATERIALS AND METHODS

Preplant Herbicide Study. A study was conducted at the LSU AgCenter Northeast Research Station near St. Joseph, LA with a natural infestation of prickly sida. The soil type was a Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) with a pH of 5.7 and organic matter content of 2.5%. Fields were prepared in the fall by double disking and bedding of rows and remained fallow until the study was initiated. Glyphosate (Roundup PowerMax, Monsanto Co., St. Louis, MO 63167) at 866 g ae ha^{-1} plus 2,4-D ester at 1064 (2,4-D LV4, Albaugh Inc., Ankernny, IA 5021) at 1064 g ae ha^{-1} was applied alone and in combination with residual herbicides to evaluate prickly sida control. Specific residual herbicides applied with glyphosate plus 2,4-D and herbicide rates are provided in Table 4.1.

The experimental design was a randomized complete block with four replications and plot size was 3 m x 9 m. Herbicides were applied March 19, 2011 and March 18, 2012 and a crop was not planted. Weed size at application was cotyledon to 2-leaf prickly sida, 10 to 20 cm henbit (*Lamium amplexicaule* L.) and buttercup (*Ranunculus sarduous* L.), and 15 to 30 cm curly dock (*Rumex crispus* L.). Treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver a volume of 140 L ha^{-1}. Visual control of prickly sida was recorded at 21 and 35 days after application (DAA). Visual ratings were based on prickly sida population, stunting, necrosis, and chlorosis were made using a 0 to 100% with 0 = no control and 100 = plant death. Additionally at the 35 DAA rating, prickly sida weed density in a randomly selected 0.3 m x 1 m area in each plot was recorded.

Table 4.1. Herbicide active ingredients, manufacturer, and rates for the preplant herbicide study for control of prickly sida in soybean production systems at the Northeast Research Station, St. Joseph, LA.

	Active ingredients	Manufacturer	Rate (g ae or ai ha^{-1})
1	Glyphosate + 2,4-D ester	Roundup PowerMax[2] + 2,4-D LV4[3]	866 + 1064
2	Flumioxazin[1]	Valor[4]	105.03
3	Flumioxazin + Chlorimuron ethyl	Valor XLT[4]	84.03 + 28.85
4	Flumioxazin + Pyroxasulfone	Fierce[4]	82.1 + 104.16
5	Flumioxazin + Chlorimuron ethyl + Thifensulfuron methyl	Envive[5]	71.56 + 22.56 + 7.11
6	Chlorimuron ethyl + Tribenuron ethyl	Canopy EX[5]	31.79 + 9.52
7	Metribuzin + Chlorimuron ethyl	Canopy DF[5]	270.15 + 44.95
8	Rimsulfuron + Thifensulfuron methyl	Resolve + Harmony SG[5]	17.51 + 17.51
9	Saflufenacil + Dimethenamid-P	Verdict[6]	24.95 + 218.82
10	Saflufenacil	Sharpen[6]	24.95
11	Sulfentrazone + Metribuzin	Authority MTZ[7]	226.87 + 340.31
12	Oxyfluorfen	Goal[8]	280.1

[1]Herbicide treatments 2 – 12 included glyphosate + 2,4-D at 866 and 1064 g ae ha^{-1}

[2] Monsanto Co., St. Louis, MO 63167

[3] Albaugh Inc., Ankenny, IA 50021

[4] Valent U.S.A. Corp., Walnut Creek, CA 94956

[5] I. E. du. Pont de Nemours and Co., Wilmington, DE 19898

[6] BASF Corp., Research Triangle Park, NC 27709

[7] FMC Corp, Agriculture Products Group Philadelphia, PA 19103

[8] Dow AgroSciences LLC, Indianapolis, IN 46268

Preplant, At-Planting, and POST Program Study. Experiments were conducted in fields with a natural infestation of prickly sida at the LSU AgCenter Northeast Research Station near St. Joseph, LA. Soil type was a Sharkey clay as previously described. Field preparation in the fall included double disking and bedding of rows, and rows remained fallow until experiments were initiated. Plot size was 3 m x 9.75 m. The study was a three-factor factorial treatment arrangement in a randomized complete block design with four replications. Factor A represented preplant treatments applied on March 19 both years. Factor B represented at-planting treatments applied on May 1, 2011 and April 26, 2012. Treatments for Factor C included early POST (EPOST) and late POST (LPOST) herbicide applications. Specific herbicide treatments are provided in Table 4.2. EPOST applications were made on June 1, 2011 and on May 15, 2012 when soybean was at V3 to V5 and prickly sida was at cotyledon to approximately 30 cm. The LPOST application was made on June 22, 2011 and on June 7, 2012 when soybean was at R1 and prickly sida was at cotyledon to approximately 30 cm.

Rainfall data before and after each herbicide application for 2011 and 2012 are presented in Table 4.3. Herbicide treatments were applied using a tractor equipped with a compressed air pressurized sprayer calibrated to deliver a volume of 140 L ha^{-1} at a spray pressure of 207 kPA. For both years of the study clethodim (Arrow 2EC, Makhteshim Agan of North America Inc., Raleigh, NC 27604) was applied to all plots at 280 g ai ha^{-1} prior to planting to eliminate glyphosate-resistant Italian ryegrass (*Lolium multiflorum* Lam.) as a variable. Asgrow 5831 (Monsanto Co., St. Louis, MO 63167) and Pioneer 94Y82 (Pioneer Hi-Bred Inc., Johnston, IA 50131) soybean was planted on May 1, 2011 and April 25, 2012, respectively. A John Deere 1700 vacuum planter (Deere and Company, Moline, IL 61625) was used to plant soybean at a rate of 6 to 8 seed per 31 cm of row and rows were spaced 102 cm apart.

The day prior to each of the preplant, at-planting, and POST applications visual ratings were made as described for the previous study. Prickly sida density was also determined the day prior to each of the applications by removing and counting prickly sida plants within a 0.305 m by 1 m randomly selected area in each plot. Due to the lack of timely rainfall in 2011 and 2012 (Table 4.3) the study was irrigated on June 6, 2011 and June 2 and June 29, 2012. Soybean plant height taken from the soil to the top of the soybean canopy at 10 random locations within each plot was recorded on June 21, 2011 and June 28, 2012 which corresponded to R3 growth stage. On August 1, 2011 and July 31, 2012 ten soybean plants at R5 growth stage were harvested at ground level in each plot and dried in the greenhouse to determine dry weights.

Table 4.2. Factors and herbicides for prickly sida control in the preplant, at-planting and POST program study in soybean at the Northeast Research Station, St. Joseph, LA.

	Factor A: PREPLANT
1	Glyphosate[1] + 2,4-D ester[2]
2	Glyphosate[1] + 2,4-D ester[2] + Chlorimuron-ethyl[3] + Tribenuron methyl[3]
	Factor B: PREEMERGE
1	NO PRE
2	Glyphosate[1]
3	Glyphosate[1] + Flumioxazin[4]+ Chlorimuron-ethyl[4] + Thifensulfuron methyl[4]
	Factor C: POSTEMERGE
1	Glyphosate[1] fb Glyphosate[1]
2	Glyphosate[1] fb Chlorimuron-ethyl[5] + Glyphosate[1]
3	Glyphosate[1] + Chlorimuron-ethyl[5] fb Glyphosate[1]
4	Glyphosate[1] + S-metolachlor[6] + Fomesafen[6] fb Glyphosate[1]

[1] Roundup PowerMax applied at 866 g ae ha^{-1}, Monsanto Co., St. Louis, MO 63167
[2] 2,4-D LV4, applied at 798 g ae ha^{-1}, Albaugh Inc., Ankenny, IA 50021)
[3] Canopy EX applied at 48.31 g ai ha^{-1}, I. E. du. Pont de Nemours and Co., Wilmington, DE 19898
[4] Envive applied at 101.23 g ai ha^{-1} I. E. du. Pont de Nemours and Co., Wilmington, DE 19898
[5] Classic applied at 8.75 g ai ha^{-1}, I. E. du. Pont de Nemours and Co., Wilmington, DE 19898
[6] Prefix applied at 1481.69 g ai ha^{-1}, Syngenta Crop Protection LLC., Greensboro, NC 27419

Insecticide and fungicide applications were made each year according to LSU AgCenter recommendations. Once soybeans reached physiological maturity, the crop was desiccated with paraquat at 560 g ai ha^{-1} plus 1% v/v crop oil to facilitate harvesting (Boudreaux and Griffin 2011). Soybean in the Preplant, At-Planting, and POST Program study were harvested September 23, 2011 and September 6, 2012 using a Massey Ferguson (Kincaid Equipment Manufacturing, Haven, KS 67543) combine equipped with a yield monitoring system produced by Juniper Systems Inc. (Juniper Systems Inc., Logan, UT 84321) that measures grain moisture content and grain yield of each plot. Grain yield per plot was adjusted to 13 percent moisture.

Table 4.3. Rainfall prior to and following preplant, at-planting, and POST treatments in the prickly sida preplant, at-planting, and POST program study at the Northeast Research Station, St. Joseph, LA.

	Rainfall (mm)	
Time period[1]	2011	2012
Preplant treatments		
14 days prior	138	61
14 days after	71	48
At-planting treatments		
7 days prior	51	13
7 days after	18	18
POST treatments		
14 days prior to EPOST	-[2]	27
14 days after EPOST	0	5
14 days prior to LPOST	25	-[3]
14 days after LPOST	26	46

[1] Preplant treatments applied March 19, 2011 and 2012; at-planting treatments applied May 1, 2011 and April 26, 2012; early POST (EPOST) treatments applied June 1, 2011 and May 15, 2012; and late POST (LPOST) treatments applied June 22, 2011 and June 7, 2012.

[2] Due to lack of rainfall soybean was furrow irrigated on June 6, 2011. Between June 7 and June 9 39 mm of rainfall was received.

[3] Due to lack of rainfall the test was furrow irrigated on June 2 and June 29, 2012.

Data for both studies was subjected to ANOVA using Standard Least Squares method in Fit Model functionality using JMP® software (JMP 2015). Treatments were considered fixed effects, whereas year and replication within year were considered random effects. Type III tests were used to test significance of fixed effects. LSMEANS were used for treatment comparison and Fisher's protected LSD was used for mean separation.

RESULTS AND DISCUSSION

Preplant Herbicide Study. In this study glyphosate plus 2,4-D ester was applied alone and in combination with residual herbicides to evaluate control of prickly sida. Complete control of the winter weeds henbit, buttercup, and curly dock and small prickly sida was observed for glyphosate plus 2,4-D (data not shown). Ten days after application (DAA) in 2011, 71.1 mm rain event occurred and in 2012, 39.4 mm of rainfall occurred within 3 DAA (data not shown) which provided activation of herbicide and encouraged emergence of prickly sida. At 21 DAA of glyphosate plus 2,4-D plus flumioxazin plus chlorimuron-ethyl plus thifensulfuron-methyl, prickly sida was controlled 90% and control was equivalent to that for flumioxazin plus chlorimuron-ethyl, flumioxazin plus pyroxasulfone, metribuzin plus chlorimuron-ethyl, and metribuzin plus sulfentrazone applied with glyphosate plus 2,4-D (68 to 81%) (Table 4.4). When glyphosate plus 2,4-D was applied alone, prickly sida control 21 DAA was 18% and control was not increased with the addition of rimsulfuron plus thifensulfuron-methyl or saflufenacil (25 and 33% control, respectively).

At 35 DAA, prickly sida control was 70 to 89% and equivalent when glyphosate plus 2,4-D was applied with flumioxazin plus chlorimuron-ethyl, flumioxazin plus pyroxasulfone, flumioxazin plus chlorimuron-ethyl plus thifensulfuron-methyl, metribuzin plus chlorimuron-ethyl, and metribuzin plus sulfentrazone (Table 4.4). At 35 DAA, the combinations of flumioxazin with chlorimuron-ethyl, pyroxasulfone, and chlorimuron-ethyl plus thifensulfuron-methyl resulted in 89% control of prickly sida which was greater than that provided by flumioxazin. Flumioxazin alone controlled prickly sida 62% which was as effective in

Table 4.4. Prickly sida control 21 and 35 days after herbicide application (DAA) and prickly sida density 35 DAA in the preplant herbicide study at the Northeast Research Station, St. Joseph, LA.[1]

Herbicide treatment	Rate (g ae or ai ha^{-1})	Prickly sida control (%) 21 DAA	Prickly sida control (%) 35 DAA	Prickly sida density (no. m^{-2}) 35 DAA
Glyphosate + 2,4-D ester[2]	866 + 1064	18 e[3]	3 f	260 abc
Flumioxazin	105	59 bc	62 bc	217 abc
Flumioxazin + chlorimuron-ethyl	84 + 30	81 ab	89 a	92 c
Flumioxazin + pyroxasulfone	82 + 104	76 ab	89 a	115 bc
Flumioxazin + chlorimuron-ethyl + thifensulfuron-methyl	72 + 23 + 7	90 a	89 a	95 bc
Chlorimuron ethyl + tribenuron-methyl	32 + 10	61 bc	68 bc	211 abc
Metribuzin + chlorimuron-ethyl	270 + 45	70 abc	75 ab	135 bc
Metribuzin + sulfentrazone	227 + 340	68 abc	70 ab	145 bc
Rimsulfuron + thifensulfuron-methyl	18 + 18	25 e	22 ef	421 a
Saflufenacil	25	33 de	38 de	286 ab
Saflufenacil + dimethenamid-P	25 + 220	52 cd	48 cd	405 a
Oxyfluorfen	280	61 bc	56 bcd	250 abc

[1] Field sites were prepared in fall by disking and bedding of rows. Henbit, buttercup, and curly dock 10 to 30 cm tall were present when herbicide treatments were applied on March 19, 2011 and March 18, 2012.

[2] Glyphosate plus 2,4-D ester (Gly + 2,4-D) at 866 + 798 g ae/ha was included in all treatments to eliminate winter weeds and to allow for evaluation of herbicide residual activity.

[3] Means within each column followed by same letter are not significantly different at P = 0.05 using Fisher's protected LSD.

controlling prickly sida as chlorimuron-ethyl plus tribenuron-methyl, metribuzin plus chlorimuron-ethyl, metribuzin plus sulfentrazone, saflufenacil plus dimethenamid-P, and oxyfluorfen (48 to 75%). In another study, Burke et al. (2002) reported flumioxazin applied PRE at 105 g ai ha^{-1} plus dimethenamid or ethafluralin controlled prickly sida 89 to 98%. Green et al. (1988) reported that metribuzin at 180 g ha^{-1} controlled prickly sida 79 to 98% compared with chlorimuron at 54 g ha^{-1} with 40 to 83% control. The combination of metribuzin at 240 g ha^{-1} with chlorimuron at 0 to 54 g ha^{-1} controlled prickly sida 75 to 100% 34 days after treatment (DAT), whereas, in the current study metribuzin plus chlorimuron-ethyl controlled prickly sida only 75%. Vidrine et al. (1996) reported 83 to 94% prickly sida control with sulfentrazone at 420 g ha^{-1} applied PRE and control was greater than for metribuzin at 420 g ha^{-1}. In this study, at 35 DAA, metribuzin at 227 g ha^{-1} plus sulfentrazone at 340 g ha^{-1} controlled prickly sida only 70%.

When residual herbicide was not applied with glyphosate plus 2,4-D prickly sida control was 3% at 35 DAA and was not increased when rimsulfuron plus thifensulfuron-methyl was applied with glyphosate plus 2,4-D (Table 4.4). Although differences in prickly sida control were observed among the herbicide treatments 21 and 35 DAA, the combination of residual herbicides with glyphosate plus 2,4-D did not decrease prickly sida density 35 DAA compared with glyphosate plus 2,4-D alone. Additionally differences in prickly sida density were not observed among treatments containing flumioxazin or between treatments containing metribuzin or saflufenacil.

Preplant, At-Planting, and POST Program Study. During the 14 day period prior to application of the preplant treatments, 138 and 61 mm of rainfall was received in 2011 and 2012, respectively (Table 4.3) During the 14 day period after preplant treatments were applied rainfall of 71 mm in 2011 and 48 mm in 2012 was received to activate herbicide and encourage germination and emergence of prickly sida.

Ratings for prickly sida control 38 to 43 days after the preplant application averaged 4% where glyphosate plus 2,4-D was applied preplant compared with 62% control where the residual herbicides chlorimuron-ethyl and thifensulfuron-methyl were applied with glyphosate plus 2,4-D (Table 4.5). The addition of residual herbicides resulted in 50% reduction in prickly sida density compared with only glyphosate plus 2,4-D applied preplant (72 vs. 145 plants m^{-2}).

Table 4.5. Prickly sida control and prickly sida density 38 and 43 days after the preplant herbicide application in 2011 and 2012, respectively, in the preplant, at-planting, and POST program study at the Northeast Research Station, St. Joseph, LA.[1]

Preplant treatment	Rate g ae or ai ha^{-1}	Prickly sida control (%)	Prickly sida density (no. m^{-2})
Glyphosate + 2,4-D ester	866 + 798	4 a[2]	145 a
Glyphosate + 2,4-D ester + chlorimuron-ethyl + tribenuron-methyl	866 + 798 + 32 + 10	62 b	72 b

[1] Field sites were prepared in fall by disking and bedding of rows. Winter weeds at 2 to 3 leaf and 7 to 10 cm tall were present when herbicide treatments were applied on March 19, 2011 and 2012.

[2] Means within each column followed by same letter are not significantly different at P = 0.05 using Fisher's protected LSD.

The day after the preplant ratings were made, soybean was planted and at-planting herbicide treatments were applied. Over the next 7 d period 18 mm of rain was received each year, assuring activation of the PRE herbicides (Table 4.3). Prickly sida control, 19 to 31 days after the at-planting herbicide application, a significant preplant by at-planting treatment interaction was observed (Table 4.6). When herbicide was not applied at-planting, prickly sida control was 2% for glyphosate plus 2,4-D applied preplant, but control was 24% for chlorimuron-ethyl plus tribenuron-methyl applied with glyphosate plus 2,4-D. In contrast, prickly sida control was 89 to 95% and equivalent when glyphosate was applied at-planting either alone or with the residual herbicides flumioxazin, chlorimuron-ethyl, and thifensulfuron-

Table 4.6. Prickly sida control and density 19 and 31 days after the at-planting herbicide application in 2011 and 2012, respectively, in the preplant, at-planting, and POST program study at the Northeast Research Station, St. Joseph, LA.

		Prickly sida control (%)				Prickly sida density (no. m^{-2})			
		At-planting treatment[2]				At-planting treatment			
Preplant treatment[1]	Rate g ae or ai ha^{-1}	None	Gly	Gly + Flumi + Chlor + Thifen	Average	None	Gly	Gly + Flumi + Chlor + Thifen	Average
Glyphosate + 2,4-D ester	866 + 798	2 c[3]	89 a	89 a	--	234	133	33	133 a
Glyphosate + 2,4-D ester + chlorimuron-ethyl + tribenuron-methyl	866 + 798 + 32 + 10	24 b	93 a	95 a	--	178	95	23	98 b
Average		--	--	--		206 a[1]	114 b	28 c	

[1] Preplant treatments were applied on March 19, 2011 and 2012.

[2] At-planting treatments included none (no herbicide), glyphosate (Gly) at 866 g ae/ha, and Gly plus flumioxazin plus chlorimuron-ethyl plus thifensulfuron-methyl (Flumi + Chlor + Thifen) at 72 + 23 + 7 g ai/ha. Treatments were applied May 1, 2011 and April 26, 2012.

[3] Means followed by same letter are not significantly different at P = 0.05 using Fisher's protected LSD.

methyl regardless of preplant herbicide treatment (Table 4.6). In the Preplant Herbicides Study discussed previously, treatments most effective on prickly sida were those containing flumioxazin and in particular flumioxazin plus chlorimuron-ethyl plus thifensulfuron-methyl (Table 4.4), the same herbicides and rates evaluated at-planting in the Preplant, At-Planting, and POST Program Study (Table 4.6). Other research has shown 89 to 98% residual control of prickly sida from PRE application of flumioxazin (Burke et al. 2002), cloransulam and cloransulam plus metribuzin (Barnes and Oliver 2004), sulfentrazone (Vidrine et al. 1996), and linuron (Jeffery at al. 1976).

For prickly sida density 19 to 31 days after the at-planting herbicide application, only the preplant treatment and at-planting treatment main effects were significant (Table 4.6). Averaged across at-planting treatments, prickly sida density was 26% less when chlorimuron-ethyl and tribenuron-methyl were applied preplant with glyphosate plus 2,4-D compared with glyphosate plus 2,4-D alone (98 vs. 133 plants m^{-2}). Averaged over the preplant treatments, prickly sida density was greatest when herbicide was not applied at-planting (206 plants m^{-2}) and lowest when glyphosate was applied with flumioxazin, chlorimuron-ethyl, and thifensulfuron-methyl (28 plants m^{-2}), an 86% reduction. For glyphosate applied alone at-planting, prickly sida density averaged 114 plants m^{-2}, 45% less than when no herbicide was applied, but 410% higher compared to prickly sida population with glyphosate plus the residual herbicides.

During the 14 day period before the EPOST application, soybean was irrigated in 2011 to assure that weeds were not drought stressed. In 2012, 27 mm of rain was received during the 14 day period prior to EPOST application (Table 4.3) and irrigation was not needed. For the 14 day period after the EPOST application in 2011 rainfall was not received and soybean and prickly sida growth were not negatively affected due to the earlier irrigation. In 2012, rainfall of 5 mm was received during the 14 day period after EPOST application.

Prickly sida control ratings made one-day prior to LPOST applications corresponded to 21 to 31 days after the EPOST application. A significant at-planting by POST treatment interaction was observed (Table 4.7). Averaged across preplant treatments of glyphosate plus 2,4-D and glyphosate plus 2,4-D plus chlorimuron-ethyl plus tribenuron-methyl, prickly sida control when herbicide was not applied at-planting was 48 to 57% for the EPOST treatments. Control for EPOST treatments averaged across preplant treatments was 79 to 87% when only glyphosate was applied at-planting and 89 to 96% when glyphosate was applied with flumioxazin, plus chlorimuron-ethyl, plus thifensulfuron-methyl at-planting. Average prickly sida control for the individual EPOST treatments was lowest when no herbicide was applied at-planting and greatest when glyphosate was applied with the residual herbicides at planting. Regardless of at-planting herbicide treatment, inclusion of the residual herbicides chlorimuron-ethyl or s-metolachlor plus fomesafen with glyphosate POST in general did not increase prickly sida control compared with glyphosate alone.

A significant preplant by at-planting treatment interaction was also observed for prickly sida control 21 to 31 days after the EPOST application (Table 4.7). When no herbicide or glyphosate alone was applied at-planting, prickly sida control averaged across EPOST treatments was greater following glyphosate plus 2,4-D plus chlorimuron-ethyl and tribenuron-methyl applied preplant compared with only glyphosate plus 2,4-D applied preplant (60 vs. 47% and 87 vs. 78%, respectively). In contrast when glyphosate plus flumioxazin, chlorimuron-ethyl, and thifensulfuron-methyl were applied at-planting, prickly sida control was equivalent regardless of preplant treatment (90 and 93%).

Table 4.7. Percent prickly sida control 21 and 31days after the early POST (EPOST) application in 2011 and 2012, respectively, in the preplant, at-planting, and POST program study at the Northeast Research Station, St. Joseph, LA.

	Preplant treatment[1]								
	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Average[4]	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Average[4]	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Average[4]
	At-planting treatment[2]								
EPOST treatment[3]	None			Gly			Gly + Flumi + Chlor + Thifen		
Gly	51	61	56 d[5]	71	86	79 c	90	91	91 a
Gly + Chlor	40	68	54 de	88	87	87 b	84	93	89 ab
Gly + Meto + Fome	44	51	48 e	84	87	86 bc	96	95	96 a
Gly	5	62	57 d	70	88	79 c	89	94	91 ab
Preplant x At-planting Avg.	47 e	60 d		78 c	87 b		90 ab	93 a	
Preplant Avg.	72	80		--	--		--	--	
At-planting Avg.	54			83			92		

[1] Preplant treatments included glyphosate plus 2,4-D ester (Gly + 2,4-D) at 866 g ae/ha + 798 g ae/ha and Gly plus 2,4-D at 866 g ae/ha + 798 g ae/ha plus chlorimuron-ethyl plus tribenuron-ethyl (Chlor + Triben) at 32 + 10 g ai/ha. Treatments were applied March 19, 2011 and 2012.

[2] At-planting treatments included none (no herbicide), glyphosate (Gly) at 866 g ae/ha, and Gly at 866 g ae/ha plus flumioxazin plus chlorimuron-ethyl plus thifensulfuron-methyl (Flumi + Chlor + Thifen) at 72 + 23 + 7 g ai/ha. Treatments were applied May 1, 2011 and April 26, 2012.

[3] EPOST treatments included glyphosate (Gly) alone at 866 g ae/ha, Gly at 866 g ae/ha plus Chlor at 9 g ai/ha, Gly at 866 g ae/ha plus s-metolachlor (Meto) plus fomesafen (Fome) at 1216 + 266 g ai/ha, and Gly alone at 866 g ae/ha. Treatments were applied June 1, 2011 and May 15, 2012. The first Gly alone treatment was to receive a follow up treatment of Gly late POST and the second Gly alone treatment was to receive Gly plus Chlor late POST.

[4] Means represent the at-planting x POST interaction and are averaged across preplant treatments.

[5] At-planting x POST interaction means followed by same letter are not significantly different at P = 0.05 using Fisher's protected LSD.

For prickly sida density determined 21 to 31 days after the EPOST application a significant effect was noted for only the at-planting treatment main effect (Table 4.8). Prickly sida density was greatest and equivalent for no herbicide at-planting (378 plants m^{-2}) and glyphosate applied alone (280 plants m^{-2}). Prickly sida density was 4 and 3 times greater where no herbicide or glyphosate alone was applied at-planting compared to glyphosate plus residual herbicides flumioxazin, chlorimuron-ethyl, and thifensulfuron-methyl were applied at-planting (378 and 280 vs. 95 plants m^{-2}).

For the final prickly sida control rating made 21 to 26 days after the LPOST application only the preplant and at-planting treatments main effects were significant (Table 4.9). Averaged across at-planting and POST treatments, prickly sida control for the preplant treatments was 84% for glyphosate plus 2,4-D and 88% for glyphosate plus chlorimuron-ethyl and tribenuron-methyl. Regardless of the preplant or the POST treatments evaluated, prickly sida control averaged 74% when herbicide was not applied at-planting and control was less than when either glyphosate or glyphosate plus the residual herbicides was applied at planting (90 and 93%, respectively). It should be noted that in the Preplant Herbicide study, prickly sida was controlled 89% at 35 DAA (Table 4.4) and control was comparable to that observed when the same treatment was evaluated in the Programs Study (Table 4.9). The fact that control was equivalent for both glyphosate plus the residual herbicides and glyphosate alone applied at planting, emphasize the value of the crop canopy in providing weed control.

For prickly sida density approximately 21 to 26 days after the LPOST application only the at-planting main effect was significant (Table 4.10). Averaged across preplant and POST treatments, prickly sida density was 49 plants m^{-2} when glyphosate was applied with flumioxazin plus chlorimuron-ethyl plus thifensulfuron-methyl at-planting. Density observed when

Table 4.8. Prickly sida density (no. m^{-2}) 21 and 31 days after the early POST (EPOST) application in 2011 and 2012, respectively, in the preplant, at-planting, and POST program study at the Northeast Research Station, St. Joseph, LA.

	Preplant treatment[1]					
	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben
	At-planting treatment[2]					
EPOST treatment[3]	None		Gly		Gly + Flumi + Chlor + Thifen	
Gly	536	615	388	204	100	100
Gly + Chlor	289	240	181	217	125	164
Gly + Meto + Fome	464	266	151	247	40	76
Gly	266	447	391	559	69	122
Preplant x At-planting Avg.	382	378	266	293	79	115
Preplant Avg.	247	224	--	--	--	--
At-planting Avg.	378 a[4]		280 a		95 b	

[1] Preplant treatments included glyphosate plus 2,4-D ester (Gly + 2,4-D) at 866 g ae/ha + 798 g ae/ha and Gly plus 2,4-D at 866 g ae/ha + 798 g ae/ha plus chlorimuron-ethyl plus tribenuron-ethyl (Chlor + Triben) at 32 + 10 g ai/ha. Treatments were applied March 19, 2011 and 2012.

[2] At-planting treatments included none (no herbicide), glyphosate (Gly) at 866 g ae/ha, and Gly at 866 g ae/ha plus flumioxazin plus chlorimuron-ethyl plus thifensulfuron-methyl (Flumi + Chlor + Thifen) at 72 + 23 + 7 g ai/ha. Treatments were applied May 1, 2011 and April 26, 2012.

[3] Early POST treatments included glyphosate (Gly) alone at 866 g ae/ha, Gly at 866 g ae/ha plus Chlor at 9 g ai/ha, Gly at 866 g ae/ha plus s-metolachlor (Meto) plus fomesafen (Fome) at 1216 + 266 g ai/ha, and Gly alone at 866 g ae/ha. Treatments were applied June 1, 2011 and May 15, 2012. The first Gly alone treatment was to receive a follow up treatment of Gly late POST and the second Gly alone treatment was to receive Gly plus Chlor late POST.

[4] Means followed by same letter are not significantly different at P = 0.05 using Fisher's protected LSD.

Table 4.9. Percent prickly sida control 21 and 26 days after the late POST (LPOST) application in 2011 and 2012, respectively, in the preplant, at-planting, and POST program study at the Northeast Research Station, St. Joseph, LA.

	Preplant treatment[1]					
	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben
	At-planting treatment[2]					
POST treatment[3]	None		Gly		Gly + Flumi + Chlor + Thifen	
Gly fb Gly	73	75	83	92	92	92
Gly + Chlor fb Gly	67	80	91	92	90	95
Gly + Meto + Fome fb Gly	67	76	91	91	93	94
Gly fb Gly + Chlor	75	76	87	90	95	96
Preplant x At-planting Avg.	71	77	88	91	93	94
Preplant Avg.	84 b[4]	88 a	--	--	--	--
At-planting Avg.	74 c		90 b		93 a	

[1] Preplant treatments included glyphosate plus 2,4-D ester (Gly + 2,4-D) at 866 g ae/ha + 798 g ae/ha and Gly plus 2,4-D at 866 g ae/ha + 798 g ae/ha plus chlorimuron-ethyl plus tribenuron-ethyl (Chlor + Triben) at 32 + 10 g ai/ha. Treatments were applied March 19, 2011 and 2012.

[2] At-planting treatments included none (no herbicide), glyphosate (Gly) at 866 g ae/ha, and Gly at 866 g ae/ha plus flumioxazin plus chlorimuron-ethyl plus thifensulfuron-methyl (Flumi + Chlor + Thifen) at 72 + 23 + 7 g ai/ha. Treatments were applied May 1, 2011 and April 26, 2012.

[3] POST treatments included glyphosate (Gly) at 866 g ae/ha EPOST followed by (fb) Gly at 866 g ae/ha LPOST, Gly at 866 g ae/ha plus Chlor at 9 g ai/ha EPOST fb Gly at 866 g ae/ha LPOST, Gly at 866 g ae/ha plus s-metolachlor (Meto) plus fomesafen (Fome) at 1216 + 266 g ai/ha EPOST fb Gly at 866 g ae/ha LPOST, and Gly at 866 g ae/ha EPOST fb Gly at 866 g ae/ha plus Chlor at 9 g ai/ha LPOST. EPOST treatments were applied June 1, 2011 and May 15, 2012 and LPOST treatments were applied June 22, 2011 and June 7, 2012.

[4] Means followed by same letter are not significantly different at P = 0.05 using Fisher’s protected LSD.

Table 4.10. Prickly sida density (no. m^{-2}) 21 and 26 days after the late POST (LPOST) application in 2011 and 2012, respectively, in the preplant, at-planting, and POST program study at the Northeast Research Station, St. Joseph, LA.

	Preplant treatment[1]					
	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben
	At-planting treatment[2]					
POST treatment[3]	None		Gly		Gly + Flumi + Chlor + Thifen	
Gly fb Gly	342	165	257	40	53	20
Gly + Chlor fb Gly	326	30	16	66	92	161
Gly + Meto + Fome fb Gly	211	56	43	99	13	56
Gly fb Gly + Chlor	148	342	313	89	33	40
Preplant x At-planting Avg.	250	125	125	72	43	59
Preplant Avg.	125	82	--	--	--	--
At-planting Avg.	180 a[4]		95 ab		49 b	

[1] Preplant treatments included glyphosate plus 2,4-D ester (Gly + 2,4-D) at 866 g ae/ha + 798 g ae/ha and Gly plus 2,4-D at 866 g ae/ha + 798 g ae/ha plus chlorimuron-ethyl plus tribenuron-ethyl (Chlor + Triben) at 32 + 10 g ai/ha. Treatments were applied March 19, 2011 and 2012.

[2] At-planting treatments included none (no herbicide), glyphosate (Gly) at 866 g ae/ha, and Gly at 866 g ae/ha plus flumioxazin plus chlorimuron-ethyl plus thifensulfuron-methyl (Flumi + Chlor + Thifen) at 72 + 23 + 7 g ai/ha. Treatments were applied May 1, 2011 and April 26, 2012.

[3] POST treatments included glyphosate (Gly) at 866 g ae/ha EPOST followed by (fb) Gly at 866 g ae/ha LPOST, Gly at 866 g ae/ha plus Chlor at 9 g ai/ha EPOST fb Gly at 866 g ae/ha LPOST, Gly at 866 g ae/ha plus s-metolachlor (Meto) plus fomesafen (Fome) at 1216 + 266 g ai/ha EPOST fb Gly at 866 g ae/ha LPOST, and Gly at 866 g ae/ha EPOST fb Gly at 866 g ae/ha plus Chlor at 9 g ai/ha LPOST. EPOST treatments were applied June 1, 2011 and May 15, 2012 and LPOST treatments were applied June 22, 2011 and June 7, 2012.

[4] Means followed by same letter are not significantly different at P = 0.05 using Fisher's protected LSD.

glyphosate was applied with the residual herbicides was equivalent to glyphosate applied alone at-planting (95 plants m^{-2}), but was 73% less than when no herbicide was applied (180 plants m^{-2}). Based on the prickly sida control and density data collected approximately 21 days after the LPOST application (Tables 4.9 and 4.10), it can be concluded that for the preplant, at-planting, and POST weed control programs evaluated, improvement in control was most affected by the inclusion of glyphosate or glyphosate plus the residual herbicides flumioxazin, chlorimuron-ethyl, and thifensulfuron-methyl at-planting. Furthermore, weed control was not substantially improved when the residual herbicides chlorimuron-ethyl plus tribenuron-methyl were included preplant and when the residual herbicides chlorimuron-ethyl, s-metolachlor, and fomesafen were applied with glyphosate POST.

For soybean height at R3 a significant preplant by at-planting interaction was observed (Table 4.11). For all at-planting treatments soybean height was greater when glyphosate plus 2,4-D plus the residual herbicides chlorimuron-ethyl and tribenuron-methyl were applied preplant compared with glyphosate plus 2,4-D alone. Additionally, soybean height was greater when glyphosate or glyphosate plus the residual herbicides flumioxazin, chlorimuron-ethyl, and tribenuron-methyl was applied at-planting compared with no herbicide applied at planting. The observed soybean height reductions are likely the result of early season competition from poor prickly sida control in those treatments (Table 4.6). For soybean dry weight determined at R5 only the preplant treatment and at-planting treatment main effects were significant (Table 4.12). Averaged across at-planting and POST treatments, soybean dry weight was 12% greater when glyphosate plus 2,4-D plus the residual herbicides were applied preplant compared with only glyphosate plus 2,4-D. Averaged across preplant and POST treatments, soybean dry weight was 29 and 23% greater when glyphosate or glyphosate plus the residual herbicides were applied at-

Table 4.11. Soybean height at R3 growth stage in the preplant, at-planting, and POST program study at the Northeast Research Station, St. Joseph, LA.[1]

	Preplant treatment[2]					
	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben
	At-planting treatment[3]					
POST treatment[4]	None		Gly		Gly + Flumi + Chlor + Thifen	
Gly fb Gly	54	63	67	79	70	78
Gly + Chlor fb Gly	53	65	73	74	68	73
Gly + Meto + Fome fb Gly	54	62	71	76	70	73
Gly fb Gly + Chlor	53	68	71	77	72	77
Preplant x At-planting Avg.	53 d[5]	64 c	70 b	77 a	70 b	75 a
Preplant Avg.	65	72	--	--	--	--
At-planting Avg.	59		73		73	

[1] Soybean height (cm) data were collected on June 21, 2011 and June 28, 2012 and represent an average for 10 randomly selected locations within each plot.

[2] Preplant treatments included glyphosate plus 2,4-D ester (Gly + 2,4-D) at 866 g ae/ha + 798 g ae/ha and Gly plus 2,4-D at 866 g ae/ha + 798 g ae/ha plus chlorimuron-ethyl plus tribenuron-ethyl (Chlor + Triben) at 32 + 10 g ai/ha. Treatments were applied March 19, 2011 and 2012.

[3] At-planting treatments included none (no herbicide), glyphosate (Gly) at 866 g ae/ha, and Gly at 866 g ae/ha plus flumioxazin plus chlorimuron-ethyl plus thifensulfuron-methyl (Flumi + Chlor + Thifen) at 72 + 23 + 7 g ai/ha. Treatments were applied May 1, 2011 and April 26, 2012.

[4] POST treatments included glyphosate (Gly) at 866 g ae/ha EPOST followed by (fb) Gly at 866 g ae/ha LPOST, Gly at 866 g ae/ha plus Chlor at 9 g ai/ha EPOST fb Gly at 866 g ae/ha LPOST, Gly at 866 g ae/ha plus s-metolachlor (Meto) plus fomesafen (Fome) at 1216 + 266 g ai/ha EPOST fb Gly at 866 g ae/ha LPOST, and Gly at 866 g ae/ha EPOST fb Gly at 866 g ae/ha plus Chlor at 9 g ai/ha LPOST. EPOST treatments were applied June 1, 2011 and May 15, 2012 and LPOST treatments were applied June 22, 2011 and June 7, 2012.

[5] Means followed by same letter are not significantly different at P = 0.05 using Fisher's protected LSD.

Table 4.12. Soybean dry weight biomass at R5 growth stage in the preplant, at-planting, and POST program study at the Northeast Research Station, St. Joseph, LA.[1]

	Preplant treatment[2]					
	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben
	At-planting treatment[3]					
POST treatment[4]	None		Gly		Gly + Flumi + Chlor + Thifen	
Gly fb Gly	183	303	301	301	287	344
Gly + Chlor fb Gly	210	267	343	250	291	317
Gly + Meto + Fome fb Gly	237	309	325	322	288	311
Gly fb Gly + Chlor	237	246	317	321	304	315
Preplant x At-planting Avg.	217	281	321	323	293	322
Preplant Avg.	277 b[5]	309 a	--	--	--	--
At-planting Avg.	249 b		322 a		307 a	

[1] Soybean dry weight biomass (g/plant) data were collected on August 1, 2011 and July 31, 2012 and represent an average for 10 randomly selected plants within each plot.

[2] Preplant treatments included glyphosate plus 2,4-D ester (Gly + 2,4-D) at 866 g ae/ha + 798 g ae/ha and Gly plus 2,4-D at 866 g ae/ha + 798 g ae/ha plus chlorimuron-ethyl plus tribenuron-ethyl (Chlor + Triben) at 32 + 10 g ai/ha. Treatments were applied March 19, 2011 and 2012.

[3] At-planting treatments included none (no herbicide), glyphosate (Gly) at 866 g ae/ha, and Gly at 866 g ae/ha plus flumioxazin plus chlorimuron-ethyl plus thifensulfuron-methyl (Flumi + Chlor + Thifen) at 72 + 23 + 7 g ai/ha. Treatments were applied May 1, 2011 and April 26, 2012.

[4] POST treatments included glyphosate (Gly) at 866 g ae/ha EPOST followed by (fb) Gly at 866 g ae/ha LPOST, Gly at 866 g ae/ha plus Chlor at 9 g/ha EPOST fb Gly at 866 g ae/ha LPOST, Gly at 1120 g ai/ha plus s-metolachlor (Meto) plus fomesafen (Fome) at 1216 + 266 g ai/ha EPOST fb Gly at 866 g ae/ha LPOST, and Gly at 866 g ae/ha EPOST fb Gly at 866 g ae/ha plus Chlor at 9 g ai/ha LPOST. EPOST treatments were applied June 1, 2011 and May 15, 2012 and LPOST treatments were applied June 22, 2011 and June 7, 2012.

[5] Means followed by same letter are not significantly different at P = 0.05 using Fisher's protected LSD.

planting, respectively, compared with no herbicide at-planting. The observed soybean dry weight reductions is likely the result of early season competition from poor prickly sida control in those treatments (Table 4.6).

For soybean yield, as was the case for prickly sida control 21 days after the LPOST application and soybean dry weight (Tables 4.9 and 4.12), only the preplant and at-planting treatment main effects were significant (Table 4.13). Averaged across at-planting and POST treatments soybean yield was increased 10% when residual herbicide was applied with glyphosate preplant compared with glyphosate alone. When glyphosate or glyphosate plus the residual herbicides was applied at-planting, yield was equivalent and averaged around 25% greater than when no herbicide was applied at-planting.

In other research, Payne and Oliver (2000) reported that sequential glyphosate applications generally provided the highest and most consistent control of weed species evaluated, including prickly sida, and soybean yield was comparable to other herbicide programs involving PRE herbicides followed by glyphosate as needed, or glyphosate in combination with selective POST herbicides. Ellis and Griffin (2002) reported that use of soil residual herbicides at soybean planting was beneficial in delaying the initial glyphosate application by 3 and 6 days and in some years only a single POST application of glyphosate was needed. However where residual herbicide was not applied at planting and two applications of glyphosate were made, weed control and soybean yield were each equivalent to glyphosate programs that included a residual herbicide at planting. Dirks et al. (2000) also reported that when two POST applications of glyphosate were used in-crop, there was no yield benefit from the inclusion of residual herbicides at planting.

Table 4.13. Soybean yield in the preplant, at-planting, and POST program study at the Northeast Research Station, St. Joseph, LA.[1]

	Preplant treatment[2]					
	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben	Gly + 2,4-D	Gly + 2,4-D ester + Chlor + Triben
	At-planting treatment[3]					
POST treatment[4]	None		Gly		Gly + Flumi + Chlor + Thifen	
Gly fb Gly	2697	3287	3630	3778	3665	3988
Gly + Chlor fb Gly	2479	3219	3746	3801	3668	3953
Gly + Meto + Fome fb Gly	2621	3321	3523	3942	3774	3598
Gly fb Gly + Chlor	3028	3262	3603	3945	3617	3823
Preplant x At-planting Avg.	2706	3272	3625	3866	3681	3840
Preplant Avg.	3340 b	3660 a	--	--	--	--
At-planting Avg.	2990 b		3750 a		3760 a	

[1] Soybean yield (kg/ha) determined after harvest on September 23, 2011 and September 6, 2012.

[2] Preplant treatments included glyphosate plus 2,4-D ester (Gly + 2,4-D) at 866 g ae/ha + 798 g ae/ha and Gly plus 2,4-D at 866 g ai/ha + 798 g ai/ha plus chlorimuron-ethyl plus tribenuron-ethyl (Chlor + Triben) at 32 + 10 g ai/ha. Treatments were applied March 19, 2011 and 2012.

[3] At-planting/PRE treatments included none (no herbicide), glyphosate (Gly) at 866 g ae/ha, and Gly at 866 g ae/ha plus flumioxazin plus chlorimuron-ethyl plus thifensulfuron-methyl (Flumi + Chlor + Thifen) at 72 + 23 + 7 g ai/ha. Treatments were applied May 1, 2011 and April 26, 2012.

[4] POST treatments included glyphosate (Gly) at 866 g ae/ha EPOST followed by (fb) Gly at 866 g ae/ha LPOST, Gly at 866 g ae/ha plus Chlor at 9 g/ha EPOST fb Gly at 866 g ae/ha LPOST, Gly at 866 g ae/ha plus s-metolachlor (Meto) plus fomesafen (Fome) at 1216 + 266 g ai/ha EPOST fb Gly at 866 g ae/ha LPOST, and Gly at 866 g ae/ha EPOST fb Gly at 866 g ae/ha plus Chlor at 9 g ai/ha LPOST. EPOST treatments were applied June 1, 2011 and May 15, 2012 and LPOST treatments were applied June 22, 2011 and June 7, 2012.

[5] Means followed by same letter are not significantly different at P = 0.05 using Fisher's protected LSD.

In northeastern Louisiana it has been observed that prickly sida can emerge as early as the first week of March and continue throughout the growing season, suggesting the need for a season-long weed management program. A weed control program option in a reduced tillage system could include glyphosate plus 2,4-D preplant to control winter weeds, glyphosate at-planting to eliminate emerged summer annual weeds, and glyphosate for broad spectrum postemergence weed control. In this research, late season prickly sida control was as high as 93% following at-planting and POST applications that did not include residual herbicides. Soybean yield was maximized with glyphosate applied both at-planting and POST, whether or not the residual herbicides flumioxazin, chlorimuron-ethyl, and thifensulfuron-methyl were included at planting or the residual herbicides chlorimuron-ethyl, s-metolachlor, or fomesafen were included POST. Of interest is that when averaged across at planting and POST treatments, a 10% yield increase was observed when the residual herbicides chlorimuron-ethyl and tribenuron-methyl were applied with glyphosate plus 2,4-D a preplant compared with glyphosate plus 2,4-D alone. This is especially noteworthy since the preplant herbicides were applied on March 19, over 170 days prior to soybean harvest. The slight increase in prickly sida control observed late-season where residual herbicide was applied preplant combined with the decrease in prickly sida density and the increase in soybean height and biomass, although not always significant, may have contributed to the observed yield increase.

In the present study emphasis was placed on control of prickly sida. In a soybean production system the presence of glyphosate-resistant weeds as well as other hard-to-control broadleaf weeds could also benefit from the inclusion of herbicides with residual activity. Although a weed control program for prickly sida that includes the predominant use of glyphosate preplant, at-planting, and postemergence can be both efficacious and economical, exclusion of herbicides with alternative modes of action would be detrimental in respect to herbicide resistance management.

LITERATURE CITED

Askew SD, Wilcut JW, Langston VB (1999) Weed management in soybean (*Glycine max*) with preplant-incorporated herbicides and cloransulam-methyl. Weed Technol 13:276-282.

Barnes JW, Oliver LR (2004) Preemergence weed control in soybean with cloransulam. Weed Technol 18:1077-1090.

Bensch CN, Horak MJ, Peterson D (2003) Interference of redroot pigweed (*Amaranthus retroflexus*), palmer amaranth (*A. palmeri*), and common waterhemp (*A. rudis*) in soybean. Weed Sci 51:37-43.

Beyers JT, Smeda RJ, Johnson WG (2002) Weed management programs in glufosinate-resistant soybean (*Glycine max*). Weed Technol 16:267-273.

Boudreaux JM, Griffin JL (2011) Application timing of harvest aid herbicides affects soybean harvest and yield. Weed Technol 25:38-43.

Burke IC, Askew SD, Wilcut JW (2002) Flumioxazin systems for weed management in North Carolina peanut (*Arachis hypogaea*). Weed Technol 16:743-748.

Carpenter J, Gianessi L (1999) Herbicide tolerant soybeans: Why growers are adopting Roundup Ready varieties. AgBioForum 2:65-72.

Cowan P, Weaver SE, Swanton CJ (1998) Interference between pigweed (*Amaranthus spp*.), barnyardgrass (*Echinochloa crus-galli*), and soybean (*Glycine max*). Weed Sci 46:566-539.

Culpepper AS, York AC, Batts RB, Jennings KM (2000) Weed management in glufosinate- and glyphosate-resistant soybean (*Glycine max*). Weed Technol 14:77-88.

Dirks JT, Johnson WG, Smeda RJ, Wiebold WJ, Massey RE (2000) Use of preplant sulfentrazone in no-till, narrow-row, glyphosate-resistant *Glycine max*. Weed Sci 48:628-639.

Eaton BJ, Russ OG, Feltner KC (1976) Competition of velvetleaf, prickly sida, and venice mallow in soybeans. Weed Sci 24:224-228.

Ellis JM, Griffin JL (2002) Benefits of soil-applied herbicides in glyphosate-resistant soybean (*Glycine max*). Weed Technol 16:541-547.

Ellis JM, Griffin JL (2003) Glyphosate and broadleaf herbicide mixtures for soybean (*Glycine max*). Weed Technol 17:21-27.

Eyherabide JJ, Cendoya MG (2002) Critical periods of weed control in soybean for full field and in-furrow interference. Weed Sci 50:162-166.

Givens WA, Shaw DR, Kruger GR, Johnson WG, Weller SC, Young BG, Wilson RG, Owen MDK, Jordan D (2009a) Survey of tillage trends following the adoption of glyphosate-resistant crops. Weed Technol 23:150-155.

Givens WA, Shaw DR, Kruger GR, Johnson WG, Weller SC, Young BG, Wilson RG, Owen MDK, Jordan D (2009b) A grower survey of herbicide use patterns in glyphosate-resistant cropping systems. Weed Technol 23:156-161.

Green JM, Obrigawitch TT, Long JD, Hutchison JM (1988) Metribuzin and chlorimuron mixtures for preemergence broadleaf weed control in soybean, *Glycine max*. Weed Technol 2:355-363.

Hager AG, Wax LM, Bollero GA (2002) Common waterhemp (*Amaranthus rudis*) interference in soybean. Weed Sci 50:607-610.

Halford C, Hamill AS, Zhang J, Doucet C (2001) Critical period of weed control in no-till soybean (*Glycine max*) and corn (*Zea mays*). Weed Technol 15:737-744.

Heap IM (2016) The International Survey of Herbicide Resistant Weeds. http:www.weedscience.com. Accessed March 15, 2016.

Jeffery LS, Connell J, McCutchen T, Overton JR (1976) Response of prickly sida and soybeans to various herbicides. Weed Sci 24:202-205.

JMP® 2016, Version 12.0.0. SAS Institute Inc., Cary, NC, 1989-2015.

Jordan DL, York AC, Griffin JL, Clay PA, Vidrine R, Reynolds DB (1997) Influence of application variables on efficacy of glyphosate. Weed Technol 11:354-362.

Knezevic SZ, Evans SP, Mainz M (2003) Row spacing influences the critical timing for weed removal in soybean. Weed Technol 17:666-673.

Norris JL, Shaw DR, Snipes CE (2001) Weed control from herbicide combinations with three formulations of glyphosate. Weed Technol 15:522-558.

Oliver LR, Klingaman TE, McClelland M, Bozsa RC (1993) Herbicide systems in stale seedbed soybean (*Glycine max*) production. Weed Technol 7:816-823.

Payne SA, Oliver LR (2000) Weed control programs in drilled glyphosate-resistant soybean. Weed Technol 14:413-422.

Rankins Jr, A, Byrd JD, Jr, Mask DB, Barnett JW, Gerard PD (2005) Survey of soybean weeds in Mississippi. Weed Technol 19:492-498.

Reddy KN (2000) Weed control in soybean (*Glycine max*) with cloransulam and diclosulam. Weed Technol 14:293-297.

Thurlow DL, Buchanan GA (1972) Competition of sicklepod with soybeans. Weed Sci 20:379-384.

Van Acker RC, Swanton CJ, Weise SE (1993) The critical period of weed control in soybeans [*Glycine max* (L.) Merr.]. Weed Sci 41:194-200.

Vangessel MJ, Ayeni AO, Majek BA (2000) Optimum glyphosate timing with or without residual herbicides in glyphosate-resistant soybean (*Glycine max*) under full-season conventional tillage. Weed Technol 14:140-149.

Vidrine, PR, Griffin JL, Jordan DL, Reynolds DB (1996) Broadleaf weed control in soybean (*Glycine max*) with sulfentrazone. Weed Technol 10:762-765.

Vidrine PR, Reynolds DB, Griffin JL (1993) Weed control in soybean (*Glycine max*) with lactofen plus chlorimuron. Weed Technol 7:311-316.

Webster TM, Coble HD (1997) Changes in weed species composition of the Southern United States: 1974 to 1995. Weed Technol 11:308-317.

Webster TM, Nichols RL (2012) Changes in the prevalence of weed species in the major agronomic crops of the Southern United States: 1994/1995 to 2008/2009. Weed Sci 60:145-157.

Wilson HP, Cole RH (1966) Morningglory competition in soybeans. Weeds 14:49-51.

CHAPTER 5
POST-HARVEST PRICKLY SIDA (SIDA SPINOSA) CONTROL

INTRODUCTION

Presence of weeds in fields late-season is often ignored because crop yield is rarely affected (Bagavathiannan and Norsworthy 2012). Weeds present at harvest can affect harvest efficiency and seed quality due to increased moisture and foreign material. Seed production from weeds can also assure weed problems in subsequent years. At the time of harvest, weed seeds can be classified based on the dispersal status and location: (1) dispersed the previous year and persisting in the soil seedbank; (2) undispersed, retained on the mother plant; (3) dispersed in the current year and on the soil surface; (4) dispersed the current year and collected by harvest equipment (Davis 2008). Weeds present in late-season comprise ones that survived early-season weed control programs and those that emerge after control measures have ceased or after the crop has been harvested (Bagavathiannan and Norsworthy 2012). Davis (2008) observed that if the ratio of undispersed seeds to seeds in the soil seedbank, for the dominant weed species was greater than or equal to 1, this indicated the potential for 1 year seed rain would replenish or augment the soil seedbank. The current year's crop, corn or soybean, affected the risk for seedbank replenishment for some weed species.

Seedbank augmentation or replenishment is a common occurrence in commercial grain production systems managed with standard herbicide programs (Davis 2008). Seed capture or destruction at harvest time may be practical, but it would require modifying harvesting equipment. The employment of management practices that target weed seed production may be most effective at reducing seed production. The development of effective management strategies that reduce weed fecundity would be aided by species-level information that identifies tactics most appropriate for a given weed spectrum. Research has demonstrated that herbicides applied to weeds at early flower or pod set can reduce potential seedbank replenishment (Bennett and Shaw 2000; Biniak and Aldrich 1986; Brewer and Oliver 2007; Clay and Griffin 2000; Fawcett and Slife 1978; Hartzler and Battles 2001; Isaacs et al. 1989; Jha and Norsworthy 2012; Maun and Cavers 1969; Taylor and Oliver 1997; Thomas et al. 2005; Walker and Oliver 2008). Seed weight reduction, seed viability, and seedling recruitment can affect presence of weed species the following season (Jha and Norsworthy 2012). Weed species capable of prolific seed production, with an extended germination window, and potential for development of herbicide resistance there should be a zero-tolerance seed production policy (Crow et al. 2015). This research indicated that POST-harvest application of paraquat alone or in combination with residual herbicides prevented seed production of Palmer amaranth (*Amaranthus palmeri* S. Wats.). The herbicide treatments effectively eliminated the addition of 1,200 seed m^{-2} or 12 million seed ha^{-1} to the soil seedbank.

In north central Kentucky and in the Delta of Mississippi prickly sida has been observed to germinate in the field from April through September (Baskin and Baskin 1984; Egley and Williams 1991). Walker and Oliver (2008) reported that prickly sida seed production was eliminated when sequential glyphosate applications at 0.42 or 0.84 kg ai ha^{-1} were initiated when the first weed in the weed complex flowered, and a single glyphosate application to prickly sida at flowering reduced seed production by 95%. Effective long-term weed management should also include strategies that reduce late-season weed seed production.

Little research has been conducted on the influence of glyphosate and 2,4-D applications on prickly sida seed production and viability. Prickly sida has become more prevalent in Louisiana crop production systems (Bill Williams, personal communication). The shift toward earlier maturing crops has resulted in late-season emergence of prickly sida both in-crop and in harvested fields. Associated seed production may be contributing to the increased presence of prickly sida in crops. Research was conducted to evaluate the influence of POST-harvest application of glyphosate and 2,4-D on prickly sida seed production and seed viability and prickly sida control from herbicides applied following corn harvest.

MATERIALS AND METHODS

Prickly Sida POST-Harvest Seed Production/Viability Study. A study was conducted in 2011, 2012, and 2013 using prickly sida grown in pots at the LSU AgCenter Northeast Research Station near St. Joseph, La. Black polyethylene pots (International Greenhouse Co., Danville, IL 61832), 20.3 cm diameter pots with 7.6 L volume capacity, were filled with a Sharkey clay soil (very-fine, smectitic, thermic Chromic Epiaquerts). In the first year of the study soil was collected from a field with a natural population of prickly sida and was placed in pots on August 2, 2011. Seed present in the soil served as the source of plants for the experiment. During the second and third year of the study soil was collected from a fallowed field that had no prior infestation of prickly sida. Prickly sida seed collected from plants grown at the Northeast Research Station were planted in pots on June 8, 2012 and June 3, 2013.

When prickly sida reached approximately the four leaf stage, plants were thinned to two plants per pot in 2011 and to one plant per pot in 2012 and 2013. An attempt was made at the thinning operation to retain uniform sized plants. Pots were hand weeded as needed. The experiment was an augmented two factor factorial conducted in a completely randomized design with 3 plants used for seed data and plant data. The first factor was herbicide treatments: glyphosate (Roundup PowerMax, Monsanto Co., St. Louis, MO 63167) at 433 g ae ha^{-1} applied in 2012 and 2013 and at 866 g ae ha^{-1} in 2011 and 2013 and 2,4-D ester (2,4-D LV4, Albaugh Inc., Ankenny, IA 50021) at 532 g ae ha^{-1} applied in 2012 and 2013 and at 1064 g ae ha^{-1} in 2011 and 2013. A nontreated was included as a comparison. The second factor was application timings based on prickly sida growth stage: beginning of flowering, when 50% of plants had begun to flower and beginning of seed set, when 50% of plants had a mature capsule with brown seed. The flowering application was made September 22, 2011; July 30, 2012; and July 19, 2013. The seed set application was made October 12, 2011; August 8, 2012; and July 31, 2013.

Herbicide treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver a volume of 140 L ha^{-1} at a spray pressure of 207 kPA. The test area was located on the lawn behind the Northeast Research Station buildings away from research fields. The potted plants to be sprayed were removed from the test area before each herbicide application and relocated to a separate area designated for the application timing. This procedure was followed to ensure that no drift or volatility injury occurred between treatments and to prevent herbicide contamination of the non-treated plants. The pots remained in their respective treatment sites for 1 to 3 days before they were returned to the study area.

To accommodate watering of plants in 2011, soaker hoses were used. The hoses were strung along the top and sides of each pot and secured to wooden stakes driven in the ground. Pots were watered as needed receiving a watering period of 2 to 3 hours or until soil was saturated. In 2012 and 2013, pots within each treatment were placed in a 2.4 m x 2.4 m x 0.1 m wooden box. A water permeable weed suppressing fabric (Fabriscape Inc., Bedford Park, IL 60638) was attached to the bottom of the wooden boxes to catch seed that may have fallen from plants prior to removal. For water, the three plants from each treatment were placed into a 53 cm wide by 70 cm long by 22 cm deep plastic container with approximately 10 to 15 cm of water. After the soil was visibly wet, pots were removed and returned to their respective boxes where they remained until the next watering event. For each year the study was terminated once a killing frost had occurred or when plant growth has ceased. Termination dates were November 15, 2011; October 22, 2012; and October 8, 2013. At termination, each plant per pot was harvested and node number was determined. Plants were dried in the greenhouse for 1 to 2 months and dry weight was recorded.

To evaluate herbicide treatment effect on seed production, mature seed capsules were removed at regular intervals from plants within a treatment and composited. A mature seed capsule was defined as a brown dry capsule with dried brown seeds visible. Prickly sida seed number was determined by hand counting all the seed collected for a treatment sample in 2011 and 2012 and by estimation based on 50 or 100 seed weight in 2013. In 2013, either all possible samples of 100 seed weight were measured or five samples of 50 seed each were measured for each treatment. Total sample weight was then measured and seed number estimated for each treatment. The method used (hand counting or estimation) was determined based on the number of seed and the amount of debris remaining after seed cleaning.

Seed removed from prickly sida plants, were stored in the lab at the Northeast Research Station and maintained at room temperature. Seed viability was determined in 2014 from 4 replicates of 50 seeds for each year of the study. Seed number varied between treatments depending on herbicide treatment. The procedure used to evaluate viability was a modified method described by Webster et al. (2015). Prickly sida seed for each treatment were soaked in a 50:50 (v/v) solution of chlorine bleach and distilled water for 5 to 10 minutes to reduce seedling disease. Once soaked, the seed were placed in a U.S. no. 20 mesh size (0.841 mm) sieve and thoroughly rinsed with distilled water. Seeds were placed on the surface of a Crocker Blue Blotter Circle paper (Anchor Paper Company, St. Paul, MN 55101) in a 9-cm petri dish and 5 or 7 ml (experiment year 2013) of a 1% distilled water/azoxystrobin (Dynasty/Quadris, Syngenta

Crop Protection LLC., Greensboro, NC 27419) (100 ml of 10% Dynasty add to 900 ml of distilled water) solution was added to reduce seedling disease. Blotter paper was firmly placed over the seed and the petri dish top was replaced and sealed with Parafilm (SPI Supplies, Structure Probe Inc., West Chester, PA 19381) to prevent moisture loss. All petri dishes were placed in a dark temperature controlled incubator set at 35 C for 14 d and seed were scored as germinated if radicle protrusion was visible, dormant if no radicle was visible and seed did not crush under forceps pressure, and non-viable if no radicle was visible and crushed under forceps pressure. Average viability percentage was calculated for each treatment for each year. Total viable seed production was estimated by multiplying total seed production for each treatment in a given year by the respective viability percentage. Since not every treatment produced seeds to test viability, data were not analyzed statistically because of imbalanced data and missing values.

The seed production and growth data were subjected to ANOVA using Standard Least Squares method in Fit Model functionality using JMP® software (JMP 2015). A mixed model with herbicide combinations and application timing as fixed effects was used. Herbicide rates in common among years (560 g ha^{-1} in 2012 and 2013 and 1120 g ha^{-1} in 2011 and 2013) were analyzed separately and years were considered random effects. Type III tests were used to test significance of fixed effects. LSMEANS were used for treatment comparison and Fisher's protected LSD was used for mean separation. Contrast analysis was used to compare herbicide main effects with the nontreated.

Prickly Sida POST-Harvest Control Study. A study was conducted in 2011, 2012, and 2013 in fields with heavy prickly sida infestation at the LSU AgCenter Northeast Research Station near St. Joseph, La. In 2011 and 2013 the soil was a Sharkey clay soil (very-fine, smectitic, thermic Chromic Epiaquerts) with a pH of 5.7 and organic matter content of 2.5%. In

2012 a Commerce silty clay loam soil (fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts) with a pH of 6.7 and organic matter content of 1.7% was used.

Specific herbicide treatments for this study are presented in Table 5.1. Treatments were arranged in a randomized complete block design with four replications. Plot size was 3.1 m x 7.5 or 9 m. In 2011, the study was conducted in a fallowed field and treatments were initiated on August 29, 2011. In 2012 and 2013, the study was conducted in a field following corn harvest and treatments were initiated on August 14, 2012 and September 11, 2013. In 2013, the study was conducted twice in the same field. Prickly sida height each year was 25 to 75 cm with some plants blooming and setting seed. Rainfall during the 2 weeks prior to and after treatment initiation totaled 6 and 104 mm in 2011, 55 and 91mm in 2012, and 0 and 151mm in 2013, respectively. Herbicide treatments were applied using a tractor mounted compressed air pressurized sprayer calibrated to deliver a volume of 140 L ha^{-1} at a spray pressure of 207 kPA.

In 2011, 2012, and 2013 visual control ratings were made 2 (data not shown) and 6 weeks after application (WAA). Prickly sida control was based on a scale of 0 to 100% with 0 = no control and 100 = no plants present. Eight WAA in 2012 and 2013 each plot was closely observed to determine if surviving prickly sida plants were able to set seed. If at least one plant in each replicate was observed with a mature brown capsule and brown seed, it was considered to have set seed. Data were expressed as number of observations per replicate for each treatment. Four replicate plots for each treatment were assessed in 2012 and eight replicate plots, two experiments with four replications each, were assessed in 2013.

Prickly sida control was subjected to ANOVA using Standard Least Squares method in Fit Model functionality using JMP® software (JMP 2015).Treatment LSMEANS were used for treatment comparison and Fisher’s protected LSD was used for mean separation.

Table 5.1. Herbicide treatments, rates, trade name, and manufacturer for the POST-harvest prickly sida control study at the Northeast Research Station, St. Joseph, LA. In 2013, the experiment was duplicated in the same field.

Treatments[1]	Rate (g ae or ai ha^{-1})	Trade name	Manufacturer
Glyphosate	866	Roundup PowerMax	Roundup PowerMax, Monsanto Co., St. Louis, MO 63167
Glyphosate + diuron	866 + 1120	Roundup PowerMax + Direx 4L	Roundup PowerMax, Monsanto Co., St. Louis, MO + Direx 4L, Makhteshim Agan of North America Inc., Raleigh, NC 27609
Glyphosate + diuron + linuron	866 + 560 + 560	Roundup PowerMax + Layby Pro	Roundup PowerMax, Monsanto Co., St. Louis, MO + Layby Pro, Tessenderlo Kerley Inc., Pheonix, AZ 85008
Glyphosate + atrazine	866 + 1120	Roundup PowerMax + Atrazine 4L	Roundup PowerMax, Monsanto Co., St. Louis, MO + Atrazine 4L, Makhteshim Agan of North America Inc., Raleigh, NC 27609
Glyphosate + 2,4-D ester	866 + 1064	Roundup PowerMax + 2,4-D LV4	Roundup PowerMax, Monsanto Co., St. Louis, MO + 2,4-D LV4, Albaugh Inc., Ankenny, IA 50021
Paraquat	560	Gramoxone SL	Gramoxone SL, Syngenta Crop Protection LLC, Greensboro, NC 24719
Paraquat + diuron	560 + 840	Gramoxone SL + Direx 4L	Syngenta Crop Protection LLC + Makhteshim Agan of North America Inc.
Paraquat + diuron + linuron	560 + 420 + 420	Gramoxone SL + Layby Pro	Syngenta Crop Protection LLC + Tessenderlo Kerley Inc.
Paraquat + atrazine	560 + 840	Gramoxone SL + Atrazine 4L	Syngenta Crop Protection LLC + Makhteshim Agan of North America Inc.
Paraquat + 2,4-D ester	560 + 798	Gramoxone SL + 2,4-D LV4	Syngenta Crop Protection LLC + Albaugh Inc.
Glufosinate	655	Liberty 280 SL	Bayer Crop Science LP, Reasearch Triangle Park, NC 27709
Glufosinate + diuron + linuron	655+ 420 + 420	Liberty 280 SL + Layby Pro	Bayer Crop Science LP + Tessenderlo Kerley Inc.
Glyphosate + 2,4-D ester + dicamba	1120 + 1064 + 560	Roundup PowerMax + 2,4-D LV4 + Banvel	Monsanto Co. + Albaugh Inc. + Arysta LifeScience North America LLC, Cary, NC 27513

[1] Crop oil concentrate was added to all of the glufosinate and paraquat treatments at 1% v/v, Superb HC, Winfield Solutions LLC, St. Paul, MN 55164

RESULTS AND DISCUSSION

Prickly Sida POST-Harvest Seed Production/Viability Study. Seeds were first produced on October 12, 2011, August 8, 2012, and July 31, 2013 which corresponded to 52 and 58 days after planting in 2012 and 2013, respectively. Seed collection dates included October 12, 25, and 30 and November 5 and 15, 2011; August 28, September 9, 14, and 22, and October 15 and 22, 2012; and July 31, August 4, 12, 20, and 28, September 2, 9, 19, and 25, and October 2, 2013. A significant herbicide treatment effect was observed for total seed production for glyphosate and 2,4-D when applied at 1/2X rate, but not when glyphosate or 2,4-D was applied at 1X rate (Table 5.2). When averaged over application timing, total seed production for prickly sida plants treated with 2,4-D or glyphosate plus 2,4-D was equivalent and averaged 78% less compared with glyphosate alone and 79% less than the nontreated. There was no significant difference in total seed production between the beginning of flowering and beginning of seed set application timings for either rate. Walker and Oliver (2008), reported that a single 0.84 kg ha^{-1} rate of glyphosate applied near or at prickly sida flowering reduced prickly sida seed production by 95%, whereas, earlier applications, based on the flowering of a weed in a weed complex, resulted in 69 to 86% seed reduction.

For percent seed viability for both herbicides at either rate, although numerical differences were observed among the herbicide and timing treatments (Table 5.2), data were not analyzed statistically due to missing values resulting from lack of seed production for certain treatments. For total viable seed produced per plant for the 1/2X herbicide rate, there was a significant effect due to herbicides but not due to application timing (Table 5.2). Averaged across application timings, total viable seed production was equivalent for 2,4-D and for glyphosate plus 2,4-D and averaged 80% less compared with glyphosate alone and 84% less than the

Table 5.2. Influence of glyphosate and 2,4-D ester applied alone and in combination to prickly sida at beginning flower (Flower) and beginning seed set (Seed set) on total seed production, seed viability, total viable seed, nodes per plant, and dry weight at the Northeast Research Station, St. Joseph, LA.[1]

	Total seed production (no. per plant)			Seed Viability (%)[2]			Total viable seed (no. per plant)			Nodes (number per plant)			Dry weight (g per plant)		
	Application[3] Timing			Application Timing			Application Timing			Application Timing			Application Timing		
Treatment	Flower	Seed set	Herbicide avg.	Flower	Seed set	Herbicide avg.	Flower	Seed set	Herbicide avg.	Flower	Seed set	Herbicide avg.	Flower	Seed set	Herbicide avg.
	------ 1/2X[4] rate (2012 and 2013) ------														
Nontreated	5173 a[5]			70			3984 a			37 a			14.5 a		
Glyphosate	4046	6038	5042 a	71	76	74	3141	4607	3084 a	22	28	25 b	10.6	14.5	12.6 a
2,4-D	529	1851	1190 b	77	33	55	445	596	521 b	29	34	31 a	7.5	6.4	7.0 b
Glyphosate + 2,4-D	1526	488	1007 b	36	48	42	1098	337	718 b	21	27	24 b	3.9	5.4	4.7 b
Timing avg.	2034	2792		61	52		1561	1847		24 b	30 a		7.3	8.8	
	------ 1X[4] rate (2011 and 2013)) ------														
Nontreated	4094			85			3662			40 a			16.8 a		
Glyphosate	3715	3909	3812	46	51	49	3385	2902	3144	24	28	26 b	11.7	13.8	12.8 a
2,4-D	25	1463	744	3	35	19	1	457	229	23	28	26 b	0.6	8.4	4.5 b
Glyphosate + 2,4-D	1381	1295	1338	44	2	23	1216	39	628	21	28	24 b	6.4	5.2	5.8 b
Timing avg.	1707	2222		31	29		1534	1133		23 b	28 a		6.2	9.1	

[1]Glyphosate applied at 433 g ae ha^{-1} in 2012 and 2013; at 866 g ae ha^{-1} in 2011 and 2013. 2,4-D ester applied at 532 g ae ha^{-1} in 2012 and 2013; 1064 g ae ha^{-1} in 2011 and 2013.

[2]Seed viability was not statistically analyzed due to imbalanced data from missing values resulting from no seed production from certain treatments.

[3]Application timings included Flower = beginning of flowering when 50% of plants had begun to flower and Seed set = beginning of seed set when 50% of plants had a mature capsule with brown seed.

[4]Glyphosate 1/2X rate = 433 g ha^{-1} and 1X = 866 g ae ha^{-1}; 2,4-D 1/2X rate = 532 g ae ha^{-1} and 1X = 1064 g ae ha^{-1}.

[5]Herbicide average and timing average means followed by the same letter or without letters for each variable are not significantly different using Fisher's Protected LSD at P = 0.05.

nontreated. Significant treatment effects were not observed for total viable seed production for the 1X rate herbicide rate.

In contrast to the seed data, a significant main effects of application timing and herbicide treatment was observed for nodes per plant for both 1/2X and 1X rates (Table 5.2). For the 1/2X herbicide rate, node number per plant averaged across herbicide treatments at termination of the experiments on November 15, 2011; October 22, 2012; and October 5, 2013 was 20% less when herbicide was applied at the beginning of flowering compared with beginning of seed set. Averaged across treatment timings, nodes per plant where 2,4-D was applied alone was 24% greater than for glyphosate alone and 29% greater than for glyphosate plus 2,4-D. There was no difference in nodes per plant between glyphosate and glyphosate plus 2,4-D, or between 2,4-D and the nontreated. Average node number per plant for glyphosate and glyphosate plus 2,4-D was 32% less compared to the nontreated. For the 1X herbicide rate node number per plant averaged across herbicide treatments was 18% less when herbicide was applied at beginning flower compared to beginning of seed set. Averaged across herbicide timing, node number per plant was reduced equally by glyphosate, 2,4-D and glyphosate plus 2,4-D and averaged 37% less than the nontreated.

For dry weight per plant, only a herbicide treatment effect was observed for the 1/2X and 1X herbicide rates (Table 5.2). For the 1/2X herbicide rate, averaged across application timing, prickly sida when treated with 2,4-D or glyphosate plus 2,4-D had a dry weight of 7 and 4.7 g $plant^{-1}$ and was not different. Dry weight of prickly sida treated with 1/2X rate of 2,4-D or glyphosate plus 2,4-D averaged 53% less than when glyphosate was applied alone and 59% less than the nontreated. Prickly sida dry weight per plant was no different for glyphosate applied alone and the nontreated. For the 1X herbicide rate averaged over application timings, prickly sida dry weight per plant was equivalent for the nontreated and glyphosate applied alone. Prickly sida dry weight per plant was no different for 2,4-D and glyphosate plus 2,4-D and averaged 59% less compared to glyphosate applied alone and 69% less compared to the nontreated. The effectiveness of 2,4-D and glyphosate plus 2,4-D in reducing total seed production per plant can be attributed to the corresponding reduction in plant dry weight. Walker and Oliver (2008) observed that prickly sida dry weight was on average reduced 55% from a single application of glyphosate at 0.84 kg ai ha^{-1}.

Prickly Sida POST-Harvest Control Study. At 6 WAA prickly sida was controlled 85% with glufosinate applied with diuron and linuron, greater than when glufosinate was applied alone (68%), but no different to that for paraquat applied with diuron (77%) or diuron and linuron (82%), and glyphosate applied with 2,4-D ester and dicamba (75%) (Table 5.3). Prickly sida control was 46% and lowest when glyphosate was applied alone and control was increased to 57 and 75% when glyphosate was applied with diuron, diuron and linuron, atrazine, and 2,4-D ester. Paraquat applied alone controlled prickly sida 64% and control was 74 to 82% when paraquat was applied with diuron, diuron and linuron, atrazine, and 2,4-D ester. In a similar study evaluating Palmer amaranth control following corn harvest, Crow et al. (2015) reported 91% or greater control of Palmer amaranth when paraquat was applied alone at 840 g ai ha^{-1} or with s-metolachlor, metribuzin, pyroxasulfone, saflufenacil, flumioxazin, pyroxasulfone plus flumioxazin, or pyroxasulfone plus fluthiacet. In the present study prickly sida control did not exceed 85%.

At 8 WAA each plot was closely observed to determine if surviving prickly sida plants were able to set seed. If at least one plant in each replicate was observed with a mature brown capsule and brown seed, that plant was considered to have produced seed. In 2012, at least one

Table 5.3. Prickly sida control 6 weeks after application (WAA) of glyphosate, glufosinate, and paraquat applied alone and in combination with other herbicides and visual observation of treatments for prickly sida seed set at the Northeast Research Station, St. Joseph, LA.

		Prickly sida control (%)[2]	Seed set (observation/replicate)[3]	
Treatment[1]	Rate (g/ha)	6 WAA	2012	2013
Glyphosate	866	46 h	4/4	8/8
Glyphosate + diuron	866 + 1120	62 fg	4/4	7/8
Glyphosate + diuron + linuron	866 + 560 + 560	75 cd	2/4	5/8
Glyphosate + atrazine	866 + 1120	57 g	4/4	8/8
Glyphosate + 2,4-D ester	866 + 1064	68 de	3/4	2/8
Paraquat	560	64 ef	4/4	8/8
Paraquat + diuron	560 + 840	77 bc	3/4	6/8
Paraquat + diuron + linuron	560 + 420 + 420	82 ab	3/4	6/8
Paraquat + atrazine	560 + 840	74 cd	3/4	8/8
Paraquat + 2,4-D ester	560 + 798	74 cd	4/4	6/8
Glufosinate	655	68 de	4/4	8/8
Glufosinate + diuron + linuron	655+ 420 + 420	85 ab	3/4	5/8
Glyphosate + 2,4-D ester + dicamba	866 + 1064 + 560	75 bc	2/4	2/8

[1]Crop oil concentrate was added to all of the glufosinate and paraquat treatments at 1% v/v.

[2]Ratings were made 2 and 6 WAA in 2011, 2012, and 2013.

[3]Eight WAA in 2012 and 2013 each plot was observed to determine if surviving prickly sida plants were able to set seed. If at least one plant in each plot/replicate was observed with a mature brown capsule and brown seed, it was considered to have set seed. Four replicate plots for each treatment were assessed in 2012 and eight replicate plots (two experiments with four replications each) were assessed in 2013.

[4]Means followed by same letters within each column are not significantly different using Fisher's Protected LSD at $P = 0.05$.

[5] For the double disk treatment a tandem disk set to cut 20 cm deep was run in opposite directions. For the mowing treatment a rotary mower at a cutting height of 5 cm was used.

prickly sida plant in 4 of the 4 replicates was observed to set seed in most of the herbicide treatments (Table 5.3). For only glyphosate applied with diuron plus linuron or with 2,4-D ester plus dicamba was seed set observed in only 2 of 4 replicates (2/4) in 2012. Seed set was observed in 3 of 4 replicates for glyphosate applied with 2,4-D ester, for glufosinate applied with diuron and linuron, and for paraquat applied with diuron and linuron, atrazine, and diuron.

In 2013, the study was conducted twice and observations were made on 8 replicates for each treatment. For most of the treatments evaluated, prickly sida seed set was observed in 7 of 8 or 8 of 8 replicates (Table 5.3). For two treatments, glyphosate applied with 2,4-D ester and with 2,4-D ester plus dicamba, seed set was observed in only 2 of 8 replicates (2/8). It is also noteworthy that seed set was observed in 5 of 8 replicates where glyphosate or glufosinate was applied with diuron plus linuron. In contrast to our research, Crow et al. (2015), observed that all herbicides treatments applied to Palmer amaranth following corn harvest prevented seed production, effectively eliminating the return of 12 million seed ha^{-1}.

Results show that none of the herbicide treatments provided complete control of prickly sida that was present in the field at corn harvest. The most effective herbicide treatments based on prickly sida control 6 WAA included glufosinate, paraquat, and glyphosate plus diuron and linuron (75 to 85%); paraquat plus diuron, atrazine, or 2,4-D ester (74 to 77%); and glyphosate plus 2,4-D ester and dicamba (75%). The effectiveness of glyphosate plus 2,4-D ester and dicamba in controlling prickly sida 75% along with decreasing seed set both years would make it a viable treatment option for prickly sida management after crop harvest in August and September.

LITERATURE CITED

Bagavathiannan MV, Norsworthy JK (2012). Late-season seed production in arable weed communities: management implications. Weed Sci 60:325-334.

Baskin JM, Baskin CC (1984) Environmental conditions required for germination of prickly sida (*Sida spinosa*). Weed Sci 32:786-791.

Bennett AC, Shaw DR (2000) Effect of preharvest desiccants on weed seed production and viability. Weed Technol 14:530-538.

Biniak BM, Aldrich RJ (1986) Reducing velvetleaf (*Abutilon theophrasti*) and giant foxtail (*Setaria faberi*) seed production with simulated-roller herbicide applications. Weed Sci 34:256-259.

Brewer CE, Oliver LR (2007) Reducing weed seed rain with late-season glyphosate applications. Weed Technol 21:753-758.

Clay PA, Griffin JL (2000) Weed seed production and seedling emergence responses to late-season glyphosate applications. Weed Sci 48:481-486.

Crow WD, Steckel LE, Hayes RM, Mueller TC (2015) Evaluation of POST-harvest herbicide applications for seed prevention of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*). Weed Technol 29:405-411.

Davis AS (2008) Weed seed pool concurrent with corn and soybean harvest in Illinois. Weed Sci 56:503-508.

Egley GH, Williams RD (1991) Emergence periodicity of six summer annual species. Weed Sci 39:595-600.

Fawcett RS, Slife FW (1978) Effects of 2,4-D and dalapon on weed seed production and dormancy. Weed Sci 26:543-547.

Hartzler RG, Battles BA (2001). Reduced fitness of velvetleaf (*Abutilon theophrasti*) surviving glyphosate. Weed Technol 15:492-496.

Heap IM (2016) The International Survey of Herbicide Resistant Weeds. http:www.weedscience.com. Accessed March 15, 2016.

Isaacs MA, Murdock EC, Toler JE, Wallace SU (1989) Effects of late-season herbicide applications on sicklepod (*Cassia obtusifolia*) seed production and viability. Weed Sci 37:761-765.

Jha P, Norsworthy JK (2012). Influence of late-season herbicide applications on control, fecundity, and progeny fitness of glyphosate-resistant palmer amaranth (*Amaranthus palmeri*) biotypes from Arkansas. Weed Technol 26:807-812.

JMP® 2015, Version 12.0.0. SAS Institute Inc., Cary, NC, 1989-2015.

Maun MA, Cavers PB (1969) Effects of 2,4-D on seed production and embryo development of curly dock. Weed Sci 17:533-536.

Taylor SE, Oliver LR (1997) Sicklepod (*Senna obtusifolia*) seed production and viability as influenced by late-season postemergence herbicide applications. Weed Sci 45:497-501.

Thomas WE, Pline-Srnić WA, Viator RP, Wilcut JW (2005) Effects of glyphosate application timing and rate on sicklepod (*Senna obtusifolia*) fecundity. Weed Technol 19:55-61.

Walker ER, Oliver LR (2008) Weed seed production as influenced by glyphosate applications at flowering across a weed complex. Weed Technol 22:318-325.

Webster EP, Hensley JB, Blouin DC, Harrell DL, Bond JA (2015) Impact of off-site deposition of glufosinate to non-Clearfield rice. Weed Technol 29:207-216.

CHAPTER 6
SUMMARY

This research concentrates on prickly sida, a weed that can emerge in northeastern Louisiana in early March and that is becoming more problematic in crops. The shift in recent years toward earlier maturing crops has resulted in late-season prickly sida emergence both in-crop and in harvested fields. Associated seed production may have contributed to increased prickly sida presence and competition with crops. This research on prickly sida specifically addresses 1) emergence periodicity from March through October in fields with silty clay loam and clay soils, 2) plant growth and seed production response to shade comparing gradual shade increase as would occur within a developing crop canopy and decrease in shade as would occur with crop senescence, 3) weed control and soybean yield using residual herbicides preplant, at-planting, and POST, and 4) POST harvest control programs to reduce seed production and seed viability using glyphosate and 2,4-D.

Results from the emergence periodicity study show that in both 2012 and 2013 regardless of soil type (Commerce silty clay loam or Sharkey clay), prickly sida was able to emerge when average soil temperature at a 3.8 cm depth was around 15 C and emergence continued through early October. The largest percentage of prickly sida emergence occurred from May through July. Total prickly sida emergence in 2012 from March through October averaged 193% (3 times) more for the Commerce compared with the Sharkey sites. In 2013 total emergence from March through October was only 12% more for the Sharkey compared with the Commerce site. The Commerce site was not tilled in the fall either year of the study and the Sharkey sites were tilled in the fall both years. This disagreement in cumulative emergence between years for the Commerce silty clay loam and the Sharkey clay sites suggests that tillage was not a major factor affecting prickly sida emergence periodicity. The prolonged emergence period for prickly sida support the need for a season long integrated weed management plan that reduces competition with the crop and seed production potential.

The shade studies results show that prickly sida is adapted to heavy shade environments and has the potential to produce a significant amount of seed when exposed to both increasing and decreasing shade levels as the growing season progresses. Under a 30% shade environment, an optimal environment for prickly sida dry matter accumulation and seed production based on this research, around 3,000 prickly sida seed were produced per plant. Although only around 550 seed $plant^{-1}$ were produced when shade levels gradually increased from 30 to 90%, this level of fecundity would be considered significant. With exposure to 90% shade in the early season followed by a gradual decrease in shade to full sun, total seed production was as high as around 8,100 seed $plant^{-1}$. Prickly sida is especially adept at producing seed later in the growing season after crop senescence and harvest.

For weed control programs, an option in a reduced tillage system could include glyphosate plus 2,4-D preplant to control winter weeds, glyphosate at-planting to eliminate emerged summer annual weeds, and glyphosate for broad spectrum postemergence weed control. In this research late season prickly sida control was as high as 93% following at-planting and POST applications that did not include residual herbicides. Soybean yield was maximized with glyphosate applied both at-planting and POST, whether or not the residual herbicides flumioxazin, chlorimuron-ethyl, and thifensulfuron-methyl were included at planting or the residual herbicides chlorimuron-ethyl, s-metolachlor, or fomesafen were included POST. Of interest is that when averaged across at planting and POST treatments, a 10% yield increase was observed when the residual herbicides chlorimuron-ethyl and tribenuron-methyl were applied with glyphosate plus 2,4-D a preplant compared with glyphosate plus 2,4-D alone. This is especially noteworthy since the preplant herbicides were applied on March 19, over 170 days prior to soybean harvest. The slight increase in prickly sida control observed late-season where residual herbicide was applied preplant combined with the decrease in prickly sida density and the increase in soybean height and biomass, although not always significant, may have contributed to the observed yield increase.

In the herbicide program study emphasis was placed on control of prickly sida. In a soybean production system the presence of glyphosate-resistant weeds as well as other hard-to-control broadleaf weeds could also benefit from the inclusion of herbicides with residual activity. Although a weed control program for prickly sida that includes the predominant use of glyphosate preplant, at-planting, and postemergence can be both efficacious and economical, exclusion of herbicides with alternative modes of action would be detrimental in respect to herbicide resistance management.

For reduction in prickly sida seed production, applications of 2,4-D at 532 g ae ha^{-1} and glyphosate at 433 g ae ha^{-1} plus 2,4-D at 560 g ae ha^{-1} were more effective in reducing total seed production per plant and total viable seed compared to the nontreated, 79 and 84% reduction, respectively. This seed reduction can be attributed to the corresponding reduction in plant dry weight.

For the POST-harvest study, results show that none of the herbicide treatments provided complete control of prickly sida that was present in the field at corn harvest. The most effective herbicide treatments based on prickly sida control 6 WAA included glufosinate, paraquat, and glyphosate plus diuron and linuron (75 to 85%); paraquat plus diuron, atrazine, or 2,4-D ester (74 to 77%); and glyphosate plus 2,4-D ester and dicamba (75%). The effectiveness of glyphosate plus 2,4-D ester and dicamba in controlling prickly sida 75% along with decreasing seed set both years would make it a viable treatment option for prickly sida management after crop harvest in August and September.

In northeastern Louisiana it has been observed that prickly sida can emerge as early as the first week of March and continue throughout the growing season, suggesting the need for a season-long weed management program. In recent years in Louisiana, growers and consultants have reported increased problems with control of prickly sida in soybean. From a long-term management approach it would be important to discourage weed seed production and replenishment of the soil seed bank. The innate ability of prickly sida to emerge and to persist under a heavy shade environment suggests that the crop itself would provide little competition for prickly sida. With corn harvest beginning in July in Louisiana and soybean harvest in August there would be ample time for established prickly sida plants to regrow or for new plants to set seed. This research shows that prickly sida seed production can occur as early as 78 days following 90% shade exposure. Although soybean yield and prickly sida control can be maximized with glyphosate only programs, the threat of herbicide resistant weeds and other difficult-to-control weeds warrant the use of soil residual herbicides. An integrated weed management strategy that includes weed control measures both early in the growing season and after crop harvest would be warranted to prevent substantial prickly sida seed production and replenishment of the soil seedbank.

VITA

Josh Thomas Copes is the middle child of Dan Copes and Cathy Fulton. He was born in 1983 in Vicksburg, Mississippi. He graduated from Tallulah Academy in Tallulah, Louisiana in May, 2001. He received his Bachelor of Science degree May, 2007, in agricultural business from the University of Louisiana at Monroe. In 2010, Josh graduated with a M.S. from Louisiana State University in the Department of Entomology under the direction of Dr. Rogers Leonard. He is currently working on a Ph.D. in the School of Plant and Environmental and Soil Sciences under the direction of Dr. James L. Griffin.