Combinations of Selected Sulfonylurea Herbicides and Diazinon for Yellow Nutsedge Control in Tomatoes

by

Matthew Clark Lollar

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
August 9, 2010

Keywords: sulfonylurea, halosulfuron, diazinon, yellow nutsedge

Approved by

Wheeler G. Foshee, III, Chair, Associate Professor of Horticulture
Glenn R. Wehtje, Professor of Agronomy and Soils
Charles H. Gilliam, Professor of Horticulture

Abstract

In 2008 and 2009 greenhouse and field studies were conducted at Auburn University's Plant Science Research Center, E.V. Smith Research Station, and Wiregrass Research and Extension Center evaluating combinations of selected sulfonylurea herbicides with the organophosphate insecticide diazinon to determine their combined effect on yellow nutsedge (*Cyperus esculentus*) control.

In 2009, studies were conducted in the greenhouse to evaluate nutsedge emergence with select preemergence applications of halosulfuron, alone and in combination with diazinon. When combined with diazinon, halosulfuron resulted in rate-dependent reductions in yellow nutsedge emergence. A significant interaction was observed with the two pesticides, which suggests they may have a combined effect on yellow nutsedge control. The highest rate of halosulfuron combined with various rates of diazinon offered the greatest level of nutsedge control, ranging from 95 to 100 percent control.

In the summer of 2008, a field study was conducted to evaluate nutsedge biomass with preemergence, sprayed and injected, applications of halosulfuron and diazinon alone and combined. A significant interaction was observed between halosulfuron and diazinon. In the summer of 2009, a similar field study was conducted but the injected applications were eliminated due to no differences between sprayed and injected treatments. A synergistic interaction between the two pesticides was observed in the first study but not in the second.

In 2009, field studies were conducted to evaluate nutsedge biomass with preemergence combinations of halosulfuron and diazinon. Polyethylene mulch was applied to the second study while the first study was left bare ground. A synergism was not observed in either study. However, the most effective treatment in the second study was the low rate of halosulfuron combined with a high rate of diazinon.

In 2009, studies were conducted in the greenhouse to evaluate nutsedge emergence with select preemergence applications of trifloxysulfuron and diazinon alone and combined. In the second study, the highest rate of trifloxysulfuron combined with the highest rate of diazinon offered the greatest level of nutsedge control. A synergistic interaction was observed between the two pesticides in the second study, suggesting that ensuing research should be conducted in the field.

Acknowledgments

The author would like to express his deepest gratitude to Dr. Wheeler G. Foshee, III for his outstanding encouragement, guidance, and support throughout the entirety of the author's degree. The author would also like to thank Dr. Glenn R. Wehtje and Dr. Charles H. Gilliam for their assistance and support along the way. Special thanks go to Tyler Monday for his friendship, encouragement, and technical expertise in the field and throughout this entire process. Appreciation is also extended to employees at Wiregrass Research and Extension Center, Plant Science Research Center, and E.V. Smith Research Station. The author would like to express gratitude to his parents, Clark and Pam Lollar, for their continuing wisdom, guidance, and love.

Table of Contents

List of Tables

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

The presence of weeds can have a significant impact on the yield potential of vegetable crops. One of the most arduous situations faced by growers worldwide is the management of weeds in vegetable crop production (Gilreath and Santos, 2004). For the most part, vegetable crops lack the ability to compete with weeds for allotted growing resources such as water, light, nutrients, and space (Gilreath and Santos, 2004). Yellow and purple nutsedge are some of the hardest weeds to manage in vegetable crops in the southeastern United States (Webster, 2002). A combination of cultural and chemical control is required for adequate nutsedge management and only a few herbicides are registered in vegetable crops for nutsedge control, which serves as a major problem (Kemble et al., 2004a).

Nutsedge belongs to the *Cyperaceae* (sedge) family and the *Cyperus* genus (Kemble et al., 2004a). It has a triangular stem with three, deeply-grooved basal leaves. *Cyperus esculentus* (yellow nutsedge) has a yellowish-brown colored seedhead, whereas *Cyperus rotundus* (purple nutsedge) has a reddish-brown colored seedhead (Colvin et al., 1992). Yellow and purple nutsedge produce achenes from aerial inflorescences and yellow nutsedge achenes typically have a 50 to 90% germination rate (Justice and Whitehead, 1946; Webster et al., 2008). However, the production of tubers is the main source of propagation for yellow nutsedge (Kemble et al., 2004a). Therefore, tuber suppression and viability reduction is the main focus for nutsedge management.

Croplands in countries worldwide are populated by nutsedge, classifying it as one of the worst weeds on the planet (Holm et al. 1977; Earl et al., 2004). Plentiful vegetative reproduction is prevalent in yellow nutsedge making it a persistent weed problem. Nutsedge has the ability to survive harsh conditions and thrive under good conditions (Tumbleson and Kommedahl, 1961; Wang et al., 2008). Their tubers are able to remain dormant through the winter then produce shoots in following growing seasons. A nutsedge tuber's main survival method is to remain viable for long periods of time (Ransom et al., 2009). Tests have shown that shoots can emerge from tubers as deep as 30.5 cm (Stoller and Wax, 1973; Ransom et al., 2009). Yellow nutsedge tubers have the potential to survive for at least 6 years in the field (Rotteveel and Naber 1993). Over the course of a year, a single plant can produce up to 1,900 shoots and 6,900 additional tubers (Tumbleson and Kommedahl 1961). Over a 10 wk growth period, a single nutsedge plant produces about 49 additional tubers (Webster et al., 2008). Ransom et al. (2009) reported a production of 20,000 additional tubers from a single parent tuber. Superior yellow nutsedge control is dependent on the suppression of the parent tuber along with the prevention of daughter tuber production (Nelson and Renner, 2002).

Documented cases have shown that yellow nutsedge can reduce corn and soybean yields by 79 and 87%, respectively (Keeley 1987; Earl et al., 2004). Such evidence validates the advantages of nutsedge control early in the season to reduce competition for water, light, and nutrients. Yellow nutsedge has also been reported to contain allelopathic compounds (Dorst and Doll 1980; Ferrel et al., 2004) and can serve as an alternative host for plant pathogens (Phatak et al., 1987; Ferrel et al., 2004). In addition, any tillage before planting multiply the problem by spreading the tubers (Kemble et al., 2004a).

Tomato and bell pepper weed control contributes heavily to production costs, amounting to about 10% of total operating costs for these crops (IFAS-UF 1999). Polyethylene is used in the production of tomatoes and peppers and has the potential to aid in nutsedge suppression (Chase et al. 1998; Webster 2005). It cannot act alone due to the fact that nutsedge can puncture and emerge through the plastic and successfully compete with other crops (Chase et al. 1998; Johnson and Mullinix, 2006). Nutsedge's desiccation of plastic mulch hinders the ability of growers to use the mulch for multiple crops, further elevating the cost of production (Webster et al., 2008).

Methyl bromide was the unmistakable leader in vegetable crop weed control in the twentieth century. But as of 2005 its availability has been severely limited due to stratospheric ozone depletion (Johnson and Mullinix, 2006; U.S. Department of Agriculture USDA, 2009). Substantial research has been administered in the hopes of finding a replacement but many alternatives (such as 1,3-dichloropropene, metam-sodium, methyl iodide, and chloropicrin) have failed due to the fact that high application rates are required and potential risks are evident (Csinos et al., 2000; Webster, 2005). An alternative to methyl bromide's efficacy, cost, ease of use, and availability has not yet surfaced (Sydorovych et al., 2008).

Glyphosate and paraquat are commonly used for yellow nutsedge control in vegetable crops. In the presence of sunlight, cells of existing nutsedge foliage are destructed by paraquat. But paraquat translocation is limited resulting in rapid foliar regrowth and tuber production (Wood and Gosnell, 1966). On the other hand, previous research has shown that glyphosate was translocated through chains of purple nutsedge tubers, which ultimately reduced tuber viability and production (Doll and Piedrahita 1982; Zandstra et al. 1974; Webster et al., 2008). Although, it should be noted that effective glyphosate rates used in these studies were two to four times greater than current recommended use rates. Previous research has also indicated that glyphosate at 0.41 kg ai/ha reduced yellow nutsedge foliar growth 23% and total tuber biomass 51% relative to the nontreated control (Webster et al., 2008). Glyphosate and paraquat suppress yellow nutsedge growth, but they are nonselective herbicides which have the potential to expose a vegetable crop to desiccation.

A viable alternative to methyl bromide are the sulfonylurea (SU) herbicides. Characteristics of SU herbicides include: low application rates (when compared to other herbicides), more selectivity to crops, and minimal harm to the environment. SU herbicides inhibit the synthesis of branched-chain amino acids: valine, leucine, and isoleucine, by targeting the acetolactate synthase (ALS) pathway (Gee and Hay, 1994; Buker et al., 2004). Visual plant symptoms such as leaf chlorosis and necrosis of the growing points do not usually occur until several days to weeks after SU herbicide application (Riethmuller-Haage et al., 2006). However, physiological and metabolic responses including rapid growth cessation occur within several hours of application. Plant responses associated with SU herbicides include: mitosis and DNA synthesis inhibition, an increase in free amino acids, a sharp decline in soluble protein levels, and a decrease in photosynthate translocation. Riethmuller-Haage et al. (2006) observed a 70% decrease in CO_2 fixation at 4 days after treatment (DAT) in greenhouse grown black nightshade treated with the SU herbicide metsulfuron. Light saturation occurred at a much lower irradiance level (400 µmol m^{-2} s^{-1}) in the treated plants as well, in these studies.

Halosulfuron is a systemic sulfonylurea (SU) herbicide that is registered for corn, vegetable crops, and turfgrass. Yellow nutsedge had to be controlled by a variety of different herbicides before the introduction of halosulfuron. Preemergence (PRE) and postemergence (POST) activity on yellow nutsedge have been observed with halosulfuron. The Food Quality

Protection Act has cancelled several herbicides creating a demand for safe alternatives such as halosulfuron (Fennimore and Richard 1999; Brandenberger et al., 2005). Nelson and Renner (2002) observed an 80% reduction in both nutsedge tuber density and fresh weight when halosulfuron was POST applied at a rate of 35 g/ha. The registered rate for halosulfuron on tomatoes is 27 to 54 g ai/ha (Monks et al., 2008).

Trifloxysulfuron is a systemic SU herbicide registered in tomatoes, cotton, and turfgrass (Minton et al., 2008). It offers postemergence (POST) control of yellow nutsedge, a few grasses, and some broadleaf weeds (Bangarwa et al., 2009). The registered rate for trifloxysulfuron on tomatoes is 14 g ai/ha (Monks et al., 2008).

Organophosphates were created around the beginning of the twentieth century by chemical manipulation of nerve gases. They inhibit acetylcholinesterase which is an enzyme responsible for the inactivation of the neurotransmitter acetylcholine (Pesando et al., 2003; Osterauer and Köhler, 2008). Organophosphates are most commonly used as insecticides, but tribufos (DEF) is classified as a herbicide and is used as a cotton defoliant (Fujioka and Casida, 2007). The use of tribufos gives credibility to the use of other organophosphates as herbicides, or in tank mixes with other herbicides.

Diazinon is an organophosphate insecticide that was first manufactured in 1952. Diazinon is an insecticide and acaricide available for a wide range of crops including fruit trees, corn, and tomatoes. It has contact, stomach, and respiratory activity against sucking and chewing insects and mites (Kidd and James, 1991). Studies have shown that diazinon is absorbed and translocated within plants (Kansouh and Hopkins, 1968). The registered application rate for diazinon on tomatoes is 280 g ai/ha (Walgenback et al., 2008).

Kansouh and Hopkins (1968) investigated the translocation of diazinon in bean plants. The study involved placing the roots of intact bean plants in individual vials containing 4 ml of ^{14}C-diazinon aqueous solution each. Plants were left in the solution for 8 days and then divided into roots, stem, primary leaves, and growing tip for analysis. Analysis of the separated plant sections indicated that around 13.5% of the ^{14}C-diazinon remained in the roots and a minimal amount was relocated to the plant stems. However, the primary leaves and terminal leaves absorbed 36% and 28% of the ^{14}C-diazinon respectively (Kansouh and Hopkins, 1968). El-Refai and Mowafy (1973) conducted a study examining the synergistic properties associated with a mixture of the herbicide propanil and diazinon. They observed diazinon translocation in rice (*Oryza sativa*) through aryl acylamidase enzyme inhibition, which is the enzyme responsible for the degradation of propanil in rice (El-Refai and Mowafy 1973). These studies are evidence that diazinon carries the potential to contribute to the phytotoxicity of halosulfuron in yellow nutsedge.

Organophosphates, such as diazinon, can be used to increase the efficacy of sulfonylurea herbicides while retaining selectivity in certain crops. Mortality for *Lolium rigidum* was increased when the organophosphate insecticide, malathion, was tank mixed with the sulfonylurea, chlorsulfuron (Christopher et al., 1994). Minton et al. (2008) observed greater translocation of trifloxysulfuron in cotton plants (*Gossypium hirsutum*) when it was mixed with malathion. Greater phytotoxicity was also observed compared to trifloxysulfuron alone (Minton et al. 2008). Rahman and James (1993) observed a higher damage percentage in corn (*Zea mays*) when the organophosphate terbufos was applied prior to the application of the sulfonylurea nicosulfuron. Corn injury has also been noted with mixtures of the sulfonylurea primisulfuron and select organophosphates (Biediger et al., 1992). These studies suggest that the synergistic interaction occurs because the insecticide increases the uptake of the sulfonylurea herbicide and decreases plant metabolism (Porpiglia et al., 1990).

Tomato production

Tomatoes (*Lycopersicon esculentum* Mill.) are members of the *Solanaceae* family. Bell peppers, hot peppers, eggplants, and Irish potatoes are also members of this family (Kemble et al., 2004b). In 2002, tomatoes had a market value of about $1.2 billion and were the second most valuable vegetable crop in the United States (Gilreath and Santos, 2005b). Alabama was ranked fourteenth in the United States in fresh market tomato production in 2007 (U.S. Department of Agriculture USDA, 2007). Tomatoes are native to tropical regions of South America and were collected by Spanish explorers in the seventeenth century (Kemble et al., 2004b). They originated in Peru and the Galápagos Islands and were first domesticated in Mexico. Tomatoes were taken to Europe in the mid-16th century where they were used for herbal remedies. Tomatoes were also grown for the ornamental value of their fruit, but they were not often eaten because they were thought to be poisonous. Their importance as a nutritious vegetable was not realized until the 20th century. George Washington Carver promoted the tomato as a good source of vitamins for the poor in Alabama (Jones 1998).

Aeration and loose soil conditions are required for high yield production because tomato plants have a branching, tap-fibrous root structure (Jones 1998). Tomatoes are a warm season crop in which transplanting is preferred. Transplants are commonly planted around April 1 in southern Alabama, April 15 in central Alabama, and April 30 in northern Alabama. Approximately 35 to 60 days after transplant are required for most tomato varieties to reach market maturity. They prefer a pH of 6.0 to 6.8 in a well-drained, sandy loam, loam, or clay loam soil. Tomatoes require a significant amount of fertilizer between 168 to 202 kg/ha of nitrogen (N) and 224 to 280 kg/ha of phosphorus (P_2O_5) and potash (K_2O) each. Before transplanting, 30 to 50 percent of the required N and K_2O and 100 percent of the required P_2O_5 is incorporated into the soil. The rest is applied through drip irrigation which is installed during the bedding process. Transplants are spaced between 45 and 60 cm apart within each plastic covered row (Kemble et al., 2004b). In commercial production, plant densities can range anywhere between 12,150 to 36,900 plants per hectare. For fresh market production, plant densities are less with a population of 10,000 to 20,000 plants per hectare (Jones 1998).

One of the biggest decisions facing a tomato grower is selection of the proper variety. The selected variety should have a potential yield greater than the average per acre yield of varieties used in the grower's state. Disease resistance to fusarium wilt and verticillium wilt should be exhibited by the selected variety. Fruit produced by the selected variety should be acceptable to the packer, shipper, wholesaler, retailer, and consumer. Desirable qualities include pack out, fruit shape, ripening ability, firmness, and flavor. Farmers should also consider horticultural qualities such as plant habit, stem type and fruit size, shape, color, smoothness, and resistance to defects (Olson et al., 2009).

Fruit quality can be improved by staking because the plants and fruit are kept off the ground and better spray coverage can be accomplished. Stakes are typically 120 to 150 cm-long by 2.5 cm square and are driven 20 to 30 cm into the soil. They are to be placed between every two plants and twine is wrapped around each stake and on the outside of each plant. The twine is fed through a PVC pipe or metal conduit in order to tie plants more efficiently. Twine that is immune to stretching and weathering is used. About 14 kg of twine is required for each acre. Plants are tied for the first time when they are between 30 and 38 cm tall. The next string is run about 15 to 20 cm above the previous one when plants reach about 45 to 55 cm in height. Most tomato varieties will require about 3 to 5 tyings over the course of the growing season. This provides support for the plant as well as the fruit (Kemble et al., 2004b).

A balance between vegetative and reproductive growth can be maintained through the practice of pruning. Moderate pruning promotes smaller vines and larger fruit that mature earlier. It also helps to control diseases by keeping plants and fruit off the ground. Plants should be pruned in the early morning after they have dried. Pinching off lateral branches (suckers), which appear in the leaf axils, is the most common method of pruning. All suckers except the one immediately below the first flower cluster should be removed. Suckers should be removed before reaching 10 cm in length (Kemble et al., 2004b).

Tomatoes are susceptible to numerous physiological disorders which are not caused by diseases or insects. Blossom-end rot (BER) is caused by calcium deficiency, most commonly due to water supply fluctuations. It can be identified as a brown, leathery rot located on the blossom end of the fruit. BER begins as a brown bruise the size of a dime, which expands as the condition progresses. High temperatures (above 32 C) make the problem worse. In order to prevent BER, soil pH is kept between 6.0 and 6.8, the proper amount of fertilizer is applied (too much at one time can induce BER), and adequate water is applied. If the plants develop BER, a calcium solution of about 1.8 kg calcium nitrate or calcium chloride per 378.5 liters of water is applied weekly. Blossom drop is a detrimental problem when day temperatures rise above 29 C and night temperatures exceed 22˚C. "Heat set" tomato varieties offer some relief for blossom drop.

Puffiness is prominent in high nitrogen and low light conditions and when the nitrogen-to-potassium ratio is not in balance. This condition is more common after rainfall accompanied by low temperatures. Catfacing and rough blossom scar most often occur when the weather is cool and cloudy at the time of bloom. “Open locule” is often classified as a type of catfacing which is usually more prevalent with a boron deficiency. Radial cracking often occurs during rainy periods accompanied by high temperatures. The fruit is more susceptible to this condition in extended sun exposure. Green fruits that are fully exposed to the sun are usually subject to concentric cracking. A uniform water supply combined with good foliage cover will help reduce fruit cracks. Sunscald is a condition of the fruit caused by prolonged exposure to the sun. This is often the result of poor foliage cover, which is either due to improper variety selection or insufficient nitrogen levels. Sunscald can also be caused by sudden exposure of the fruit to sunlight. Gray wall (or blotchy ripening) is most severe in excessive nitrogen levels, poor soil drainage, unbalanced nitrogen-to-potassium ratios, and low soil pH (Kemble et al., 2004b).

Irrigation is a requirement for a successful tomato operation. Tomatoes are made up of 85 to 95 percent water which contributes heavily to salable weight. Tomatoes require 2.5 to 3.8 cm of water each week. Undersized fruit, blossom-end rot, and growth cracks are all results of insufficient watering. In tomato production, insufficient watering results in a significant number of culls. Tomatoes require a continuous supply of moisture from establishment through the final harvest. Drip irrigation is considered the most efficient means to supply constant moisture. The system should be run daily during times of peak water need such as heavy fruit load, high temperatures, and low relative humidity (Kemble et al., 2004b).

Polyethylene mulch is extremely beneficial to tomato growers. It accelerates plant growth and development by increasing soil temperature. Plastic mulch also reduces soil compaction and crusting, ground rot of fruit, evaporation, and competition from weeds. Black plastic is usually used for spring plantings because it hastens maturity and increases yields. White or white-on-black plastic is best for summer and fall plantings when cooling the soil is more desired. Polyethylene mulch increases profits by producing earlier and larger yields of high quality produce (Kemble et al., 2004b).

Polyethylene mulch is used in fresh market tomato production to control soil humidity and to suppress disease and weed pressure. However, yellow nutsedge has the ability to penetrate the film and successfully compete with the tomato crop (Gilreath and Santos, 2005a). In an ideal situation, plastic mulch can be used for multiple cropping cycles. Nutsedge plants negate this ideal situation by completely desiccating the plastic mulch (Webster et al., 2008). Prior to 2005, soil fumigation before laying plastic mulch was an effective means of weed control. However, as of 2005, the effective fumigant methyl bromide has been off the market (Johnson and Mullinix, 2006). Hence, there exists a high demand to find alternative methods for nutsedge control in fresh market tomato production.

LITERATURE CITED

Bangarwa, S. K., J. K. Norsworthy, and E. E. Gbur. 2009. Integration of a brassicaceae cover crop with herbicides in plasticulture tomato. Weed Technol. 23:280-286.

Biediger, D. L., P. A. Baumann, D. N. Weaver, J. M. Chandler, and M. G. Merkle. 1992. Interactions between primisulfuron and selected soil-applied insecticides in corn (*Zea mays*). Weed Technol. 6:807-812.

Brandenberger, L. P., R. E. Talbert, R. P. Wiedenfeld, J. W. Shrefler, C. L. Webber III, and M. S. Malik. 2005. Effects of halosulfuron on weed control in commercial honeydew crops. Weed Technol. 19:346-350.

Buker, III, R. S., B. Rathinasabapathi, W. M. Stall, G. MacDonald, S. M. Olson. 2004. Physiological basis for differential tolerance of tomato and pepper to rimsulfuron and halosulfuron: site of action study. Weed Sci. 52:201-205.

Chase, C. A., T. R. Sinclair, D. G. Shilling, J. P. Gilreath, and S. J. Locascio. 1998. Light effects on rhizome morphogenesis in nutsedges (*Cyperus* spp): implications for control by soil solarization. Weed Sci. 47:467-472.

Christopher, J. T., C. Preston, and S. Powles. 1994. Malathion antagonizes metabolism-based chlorsulfuron resistance in *Lolium rigidum*. Pesticide Biochem. and Physiol. 49:172-182.

Colvin, D. L., R. Dickens, J. W. Everest, D. Hall, and L. B. McCarty. 1992. Weeds of southern turfgrass. Alabama Cooperative Extension System Alabama A&M and Auburn Universities. P. 14, 19.

Csinos, A. S., D. R. Sumner, W. C. Johnson, A. W. Johnson, R. M. McPherson, and C. C. Dowler. 2000. Methyl bromide alternatives in tobacco, tomato and pepper transplant production. Crop Protection 19:39-49.

Doll, J. D. and W. Piedrahita. 1982. Effect of glyphosate on the sprouting of *Cyperus rotundus* L. tubers. Weed Res. 22:123-128.

Dorst, D. C. and J. D. Doll. 1980. The allelopathic effect of yellow nutsedge (*Cyperus esculentus*) on corn (*Zea mays*) and soybeans (*Glycine max*). Weed Sci. 28:229-233.

Earl, H. J., J. A. Ferrell, W. K. Vencill, M. W. van Iersel, M. A. Czarnota. 2004. Effects of three herbicides on whole-plant carbon fixation and water use by yellow nutsedge (*Cyperus esculentus*). Weed Sci. 52:213-216.

El-Refai, A. R. and M. Mowafy. 1973. Interaction of propanil with insecticides absorbed from soil and translocated into rice plants. Weed Sci. 21:246-248.

Fennimore, S. A. and S. J. Richard. 1999. Screening of Low Rate Herbicides in Vegetable Crops. Moscow, ID: West. Soc. Weed Sci. Res. Prog. Rep. Pp. 44-46.

Ferrel, J. A. and H. J. Earl, and W. K. Vencill. 2004. Duration of yellow nutsedge (*Cyperus esculentus*) competitiveness after herbicide treatment. Weed Sci. 52:24-27.

Fujioka, K., J. E. Casida. 2007. Glutathione s-transferase conjugation of organophophorus pesticides yields s-phospho-, s-aryl-, and s-alkylglutathione derivatives. Chem. Res. Toxicol. 20:1211-1217.

Gee, S. K. and J. V. Hay. 1994. Recent developments in the chemistry of sulfonylurea herbicides. Pages 15-16 *in* J. Stetter and W. Ebing, eds. Chemistry of Plant Protection-Herbicides Inhibiting Branched-Chain Amino Acid Biosynthesis. Berlin: Springer-Verlag.

Gilreath, J. P. and B. M. Santos. 2004. Efficacy of methyl bromide alternatives on purple nutsedge (*Cyperus rotundus*) control in tomato and pepper. Weed Technol. 18:341-345.

Gilreath, J. P. and B. M. Santos. 2005a. Efficacy of 1,3-dichloroprpene plus chloropicrin in combination with herbicides on purple nutsedge (*Cyperus rotundus*) control in tomato. Weed Technol. 19:137-140.

Gilreath, J. P. and B. M. Santos. 2005b. Purple nutsedge (*Cyperus rotundus*) control with fumigant and pebulate combinations in tomato. Weed Technol. 19:575-579.

Holm, L. G., D. C. Plunknett, J.V. Pancho, and J.P. Herberger. 1977. The World's Worst Weeds: Distribution and Biology. Honolulu, HI: Univ. Press of Hawaii. Pp. 125-133.

[IFAS-UF] Institute of Food and Agricultural Sciences, University of Florida. 1999. Cost of Production for Florida Vegetables, 1997-98: Web page: http://www.agbuscenter.ifas.ufl.edu.

Johnson III, W. C. and B. G. Mullinix Jr. 2006. Yellow nutsedge (*Cyperus esculentus*) control with metam-sodium in transplanted cantaloupe (*Cucmis melo*). Crop Protection 26:867-871.

Jones Jr., J. B. 1998. Tomato plant culture: in the field, greenhouse, and home garden. CRC Press LLC, Boca Raton, FL.

Justice, O. L. and M. D. Whitehead. 1946. Seed production, viability, and dormancy in the nutgrasses *Cyperus rotundus* and *C. esculentus*. J. Agric. Res. 73:303-318.

Kansouh, A. S. H. and T. L. Hopkins. 1968. Diazinon absorption, translocation, and metabolism in bean plants. J. Agr. Food Chem. 16:446-450.

Keeley, P. E. 1987. Interference of interaction of purple nutsedge and yellow nutsedges (*Cyperus rotundus* and *C. esculentus*) in crops. Weed Technol. 1:74-81.

Kemble, J. M., M. G. Patterson, and J. W. Everest. 2004a. Nutsedge control in commercial vegetables. Alabama Cooperative Extension System Alabama A&M and Auburn Universities. ANR-1073.

Kemble, J. M., T. W. Tyson, and L. M. Curtis. 2004b. Guide to commercial staked tomato production in Alabama. Alabama Cooperative Extension System Alabama A&M and Auburn Universities. ANR-1156.

Kidd, H. and D. R. James (eds.) 1991. The Agrochemicals Handbook. 3rd ed. Unwin Brothers Limited, Old Woking, Surrey, U.K.

Minton, B., M. Matocha, and S. Senseman. 2008. The influence of malathion on trifloxysulfuron absorption and translocation in cotton. Cotton Sci. 12:48-52.

Monks, D. W., K. M. Jennings, W.E. Mitchem. 2008. Chemical weed control in vegetable crops. P. 255. In: Vegetable Crop Handbook for Southeastern United States.

Nelson, K. A. and K. A. Renner. 2002. Yellow nutsedge (*Cyperus esculentus*) control and tuber production with glyphosate and ALS-Inhibiting herbicides. Weed Technol. 16:512-519.

Olson, S. M., W. M. Stall, G.E. Vallad, S.E. Webb, T.G. Taylor, S.A. Smith, E.H. Simonne, E. McAvoy, and B.M. Santos. 2009. Tomato production in Florida. Institute of Food and Agricultural Sciences, Univ. of Florida. Chapter 23.

Osterauer, R., H-R. Köhler. 2008. Temperature-dependent effects of the pesticides thiacloprid and diazinon on the embryonic development of zebrafish (*Danio rerio*). Aquatic Toxicology 86:485-494.

Pesando, D., Huitorel, P., Dolcini, V., Angelini, C., Guidetti, P., Falugi, C., 2003. Biological targets of neurotoxic pesticides analysed by alteration of developmental events in the Mediterranean sea urchin, *Paracentrotus lividus*. Mar. Environ. Res. 55, 39-57.

Phatak, S. C., M. B. Callaway, and C. S. Vavrina. 1987. Biological control and its integration in weed management systems of purple and yellow nutsedge (*Cyperus rotundus* and *C. esculentus*). Weed Technol. 1:84-91.

Porpiglia, P. J., G. R. Gillespie, and M. D. Johnson. 1990. Enhanced CGA-136872 activity in combination with insecticides. Proc. of the Weed Sci. Soc. of Amer. 30:6.

Rahman, A., T. K. James. 1993. Enhanced activity of nicosulfuron in combination with soil-applied insecticides in corn (*Zea mays*). Weed Technol. 7:824-829.

Ransom, C. V., C. A. Rice, and C. C. Shock. 2009. Yellow nutsedge (*Cyperus esculentus*) growth and reproduction in response to nitrogen and irrigation. Weed Sci. 57:21-25.

Riethmuller-Haage, I., L. Bastiaans, M. J. Kropff, J. Harbinson, and C. Kempenaar. 2006. Can photosynthesis-related parameters be used to establish the activity of acetolactate synthase-inhibiting herbicides on weeds? Weed Sci. 54:974-982.

Rotteveel, A. J. W. and H. Naber. 1993. Decline of yellow nutsedge (*Cyperus esculentus*) when tuber formation is prevented. Brighton Crop Prot. Conf.: Weeds. Brighton, UK, 22-25 November 1993.1:311-316.

Stoller, E. and L. Wax. 1973. Yellow nutsedge shoot emergence and tuber longevity. Weed Sci. 53:839-845.

Sydorovych, O., C. D. Safley, R. M. Welker, L. M. Ferguson, D. W. Monks, K. Jennings, J. Driver, and F. J. Louws. 2008. Economic evaluation of methyl bromide alternatives for the production of tomatoes in North Carolina. Hort. Technol. 18(4):705-713.

Tumbleson, M. E. and T. Kommedahl. 1961. Reproductive potential of *Cyperus esculentus* by tubers. Weeds 9:646-653.

U.S. Department of Agriculture. 2007. 2007 Census of Agriculture – State Data: Table 30. 11 Nov. 2009. http://www.agcensus.usda.gov/Publications/2007/Full_Report/.

U.S. Department of Agriculture. 2009. Methyl bromide. Agricultural Research Service. 10 Sept. 2009. http://www.ars.usda.gov/Research/docs.htm?docid=10408.

Walgenback, J., M. Abney, G. Kennedy, P. Smith, R. Bessin, A. Sparks, D. Riley, M. Layton, F. Hale. 2008. Insect control for commercial vegetables. P.155. In: Vegetable Crop Handbook for Southeastern United States.

Wang, G., M. E. McGiffen Jr., E. J. Ogbuchiekwe. 2008. Crop rotation effects on *Cyperus rotundus* and *C. esculentus* population dynamics in southern California vegetable production. Weed Res. 48, 420-428.

Webster, T. M. 2002. Weed survey-southern states: vegetable, fruit and nut crops subsection. Proc. South. Weed Sci. Soc. 55:237-258.

Webster, T. M. 2005. Mulch type affects growth and tuber production of yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*Cyperus rotundus*). Weed Sci. 53:834-838.

Webster, T. M., T. Grey, J. W. Davis, and A. S. Culpepper. 2008. Glyphosate hinders purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*Cyperus esculentus*) tuber production. Weed Sci. 56:735-742.

Wood, G. H. and J. M. Gosnell. 1966. Some factors affecting the translocation of radioactive paraquat in *Cyperus* species. Proc. So. Afr. Sugar Technol. Assoc. 286-292.

Zandstra, B. H., C. K. Teo, and R. K. Nishimoto. 1974. Response of purple nutsedge to repeated applications of glyphosate. Weed Sci. 22:230-232.

CHAPTER 2

EVALUATION OF HALOSULFURON AND DIAZINON COMBINATIONS FOR THE MANAGEMENT OF YELLOW NUTSEDGE

Matthew C. Lollar, Wheeler G. Foshee III, Glenn R. Wehtje, and Charles H. Gilliam

Abstract: Greenhouse studies were conducted in 2009 at Auburn University's Plant Science Research Center to determine effects of halosulfuron and diazinon combinations for yellow nutsedge control. Treatments consisted of a factorial arrangement of 5 rates of halosulfuron (0, 14, 21, 28, and 35 g a.i./ha) and 5 rates of diazinon (0, 140, 280, 420, and 560 g a.i./ha); yielding 25 separate treatments. A completely randomized design (CRD) was observed. About 30 days after application (DAA), when nutsedge emergence was abundant, biomass was collected. Halosulfuron resulted in a rate-dependent reduction in yellow nutsedge emergence. The highest rate of halosulfuron (35 g ai/ha) combined with various rates of diazinon offered the greatest level of nutsedge control, ranging from 95 to 100% control. However, the much lower rate of halosulfuron (14 g ai/ha) combined with the medium rate of diazinon (280 g ai/ha) was able to control emergence by 96 percent and would cost significantly less. Field studies were conducted in the summers of 2008 and 2009 at Auburn University's E. V. Smith Research Center in Tallassee, Alabama. In the first study, treatments consisted of an augmented factorial arrangement of two rates of halosulfuron (39 and 53 g a.i./ha), three rates of diazinon (0, 1.12, and 2.24 kg a.i./ha), and two types of application (sprayed on soil surface and injected via irrigation). A nontreated control was included, yielding 13 treatments. A completely randomized design (CRD) was observed. In the second study, treatments consisted of a factorial

arrangement of three rates of halosulfuron (21, 28, and 35 g a.i./ha) and four rates of diazinon (0, 140, 280, and 420 a a.i./ha). A nontreated control was included, yielding 13 treatments. A CRD was observed. All treatments were sprayed in the second study. About 30 DAA, when the nutsedge population was prominent, numerical puncture data and weed biomass were collected for each entire plot in both studies. In the first study, ANOVA revealed the interaction between halosulfuron and diazinon was significant (P = 0.0616). In the second study, ANOVA revealed the interaction between halosulfuron and diazinon was not significant (P = 0.3863).

Nomenclature: halosulfuron; diazinon; yellow nutsedge (*Cyperus esculentus*); sulfonylurea; PRE; POST; organophosphate

Abbreviations: SU, sulfonylurea; PRE, preemergence; POST, postemergence; DAA, days after application; CRD, completely randomized design

INTRODUCTION

Croplands in countries worldwide are populated by nutsedge classifying it as one of the worst weeds on the planet (Holm et al. 1977; Earl et al., 2004). Plentiful vegetative reproduction is prevalent in yellow nutsedge making it a persistent weed problem. Nutsedge has the ability to survive harsh conditions and thrive under good conditions due to prolific vegetative reproduction (Tumbleson and Kommedahl, 1961; Wang et al., 2008). Their tubers are able to remain dormant through the winter then produce shoots in following growing seasons (Ransom et al., 2009). Documented cases have shown that yellow nutsedge can reduce corn and soybean yields by 79 and 87%, respectively (Earl et al., 2004). Yellow nutsedge has also been reported to contain allelopathic compounds (Dorst and Doll 1980; Ferrel et al., 2004) and can serve as an alternative host for plant pathogens (Phatak et al., 1987; Ferrel et al., 2004). Such evidence validates the advantages of nutsedge control early in the season to reduce competition for water, light, and nutrients (Keeley 1987; Earl et al., 2004). In addition, any tillage before planting multiplies the problem by spreading tubers (Kemble et al., 2004). A combination of cultural and chemical control is required for adequate nutsedge management and only a few herbicides are registered in vegetable crops for nutsedge control (Kemble et al., 2004).

Polyethylene mulch is used in the production of tomatoes and has the potential to aid in nutsedge suppression (Chase et al. 1998; Webster 2005). It cannot act alone due to the fact that nutsedge can puncture and emerge through the plastic and successfully compete with other crops (Chase et al. 1998; Johnson and Mullinix, 2006). Nutsedge's desiccation of plastic mulch hinders the ability of growers to use the mulch for multiple crops, further elevating the cost of production (Webster et al., 2008).

Halosulfuron is a systemic sulfonylurea (SU) herbicide that is registered for corn, vegetable crops, and turfgrass. Yellow nutsedge had to be controlled by a variety of different herbicides before the introduction of halosulfuron. Preemergence (PRE) and postemergence (POST) activity on yellow nutsedge have been observed with halosulfuron. The Food Quality Protection Act has cancelled several herbicides creating a demand for safe alternatives such as halosulfuron (Fennimore and Richard 1999; Brandenberger et al., 2005). Nelson and Renner (2002) observed an 80% reduction in both nutsedge tuber density and fresh weight when halosulfuron was POST applied at a rate of 35 g/ha. The registered rate for halosulfuron on tomatoes is 27 to 54 g ai/ha (Monks et al., 2008).

Diazinon is an organophosphate insecticide that was first manufactured in 1952. Diazinon is an insecticide and acaricide available for a wide range of crops including fruit trees, corn, and tomatoes. It has contact, stomach, and respiratory activity against sucking and chewing insects and mites (Kidd and James, 1991). Studies have shown that diazinon is absorbed and translocated within plants (Kansouh and Hopkins, 1968). The registered application rate for diazinon on tomatoes is 280 g ai/ha (Walgenback et al., 2008).

Organophosphates, such as diazinon, can be used to increase the efficacy of sulfonylurea herbicides while retaining selectivity in certain crops. Mortality for *Lolium rigidum* was increased when the organophosphate insecticide, malathion, was tank mixed with the sulfonylurea, chlorsulfuron (Christopher et al., 1994). Minton et al. (2008) observed greater translocation of trifloxysulfuron in cotton plants (*Gossypium hirsutum*) when it was mixed with malathion. Greater phytotoxicity was also observed compared to trifloxysulfuron alone (Minton et al. 2008). Rahman and James (1993) observed a higher damage percentage in corn (*Zea mays*) when the organophosphate terbufos was applied prior to the application of the sulfonylurea nicosulfuron. Corn injury has also been noted with mixtures of the sulfonylurea primisulfuron and select organophosphates (Biediger et al., 1992). These studies suggest that the synergistic interaction occurs because the insecticide increases the uptake of the sulfonylurea herbicide and decreases plant metabolism (Porpiglia et al., 1990).

The objective of this study was to evaluate PRE-applied halosulfuron and diazinon tank mixtures within a controlled environment in order to determine respectable rates for field application.

MATERIALS AND METHODS

Greenhouse Studies

Greenhouse studies were conducted in 2009 at Auburn University's Plant Science Research Center (PSRC). The first study was conducted in March 2009 and the study was repeated in May 2009. Styrofoam cups (400 ml) were filled with a Marvyn sandy loam soil (fine-loamy, kaolinitic, thermic type Kanhapludults) (USDA series description) excavated from

Auburn University's E. V. Smith Research Center (EVS). Three pre-germinated yellow nutsedge tubers were planted at a depth of 2.5 cm in each cup. Treatments consisted of a factorial arrangement of 5 rates of halosulfuron (0, 14, 21, 28, and 35 g a.i./ha) and 5 rates of diazinon (0, 140, 280, 420, and 560 g a.i./ha); yielding 25 separate treatments. Each treatment was replicated 6 times. A completely randomized design was observed. Treatments were applied with a compressed air powered spray booth manufactured by DeVries Manufacturing (Hollandale, MN). The spray booth was equipped with a 8002VS nozzle which rode along a stainless steel shaft and delivered 280 liters per hectare (L/ha). Approximately 30 days after application (DAA) when nutsedge was fully emerged, nutsedge biomass was taken for each cup.

Field Studies

The first field study was conducted in September 2008 at Auburn University's E. V. Smith Research Station (EVS) on a Marvyn sandy loam soil (fine-loamy, kaolinitic, thermic type Kanhapludults) (USDA series description) with a pH of 6.0. Treatments consisted of an augmented factorial arrangement of two rates of halosulfuron (39 and 53 g a.i./ha), three rates of diazinon (0, 1.12, and 2.24 kg a.i./ha), and two types of application (sprayed on soil surface and injected via irrigation). A nontreated control was included, yielding 13 treatments. A completely randomized design (CRD) was observed. The sprayed treatments were applied with a CO_2 back-pack sprayer calibrated to deliver 280 L/ha. The sprayer was equipped with two, 11005 spray nozzles spaced 45 cm apart on the boom. Injected treatments were applied using a Dosatron® water driven proportional injector (Dosatron USA Clearwater, FL.) set to deliver a ratio of 1:64.

A subsequent study was conducted in July 2009 at Auburn University's E. V. Smith Research Station (EVS) on a Marvyn sandy loam soil (fine-loamy, kaolinitic, thermic type

Kanhapludults) (USDA series description) with a pH of 6.0. Treatments consisted of a factorial arrangement of three rates of halosulfuron (21, 28, and 35 g a.i./ha) and four rates of diazinon (0, 140, 280, and 420 a a.i./ha). A nontreated control was included, yielding 13 treatments. A completely randomized design (CRD) was observed. Treatments were applied with a CO_2 back-pack sprayer calibrated to deliver 280 L/ha. The sprayer was equipped with two, 11005 spray nozzles spaced 45 cm apart on the boom.

The objective of both studies was to evaluate nutsedge control and its ability to pierce through plastic mulch so no crops were planted. The soil was prepared and shaped into seven parallel beds. Individual plots were 7.62 m long with a 0.61 m alley at both ends of each plot. After application of the sprayed treatments, drip-tape and polyethylene mulch were applied to all the rows. Then, in the first study, one injected treatment at a time was connected using 0.635 cm tubing spliced into the drip-tape for each treatment; connecting the appropriate plots for each treatment. Approximately 30 days after application (DAA), yellow nutsedge biomass was collected for each entire plot in both studies and expressed as percent control.

Statistical analysis was conducted using a general linear model with the PROC GLM procedure of SAS Version 9.1 (SAS Institute, Cary, NC) for fresh weight data.

RESULTS AND DISCUSSION

Greenhouse Studies

Analysis of variance (ANOVA) revealed no differences between the two studies, therefore data were pooled. ANOVA revealed the main effect of halosulfuron was significant ($P < 0.0001$) as well as the interaction between halosulfuron and diazinon ($P < 0.0001$) (Table 1). Therefore, the two pesticides were interactive with respect to their ability to control yellow nutsedge. Halosulfuron resulted in a rate-dependent reduction in yellow nutsedge emergence

(Table 1). $LSD_{0.05}$ between any two individual treatment means was equal to 2. Christopher et al. (1994) showed similar results when the sulfonylurea herbicide chlorsulfuron was combined with the organophosphate insecticide malathion. *Lolium rigidum* survival rate was reduced by 30% when chlorsulfuron (8 g ai/ha) was sprayed in the presence of malathion (1 kg ai/ha) compared to the rate of chlorsulfuron sprayed alone.

A synergism between halosulfuron and diazinon was observed in the greenhouse, suggesting that ensuing research should be conducted in the field. The highest rate of halosulfuron (35 g ai/ha) combined with each rate of diazinon controlled nutsedge ≥ 95%. However, the much lower rate of halosulfuron (14 g ai/ha) combined with the medium rate of diazinon (280 g ai/ha) controlled emergence by 96% and would cost significantly less. The estimated cost to-date for halosulfuron at the recommended rate of 70 g ai/ha is $102.80. Per hectare for cost diazinon at the recommended rate of 560 g ai/ha is $13.91. Therefore, the total cost per hectare for this tank mixture (14 g ai/ha halosulfuron + 280 g ai/ha diazinon) would be $20.56/ha halosulfuron + $6.95/ha diazinon, totaling to $27.51/ha. This is a total savings of $75.29 compared to the recommended rate of halosulfuron (70 g ai/ha) applied alone, which represents over 70% potential savings for producers. Also, the added benefit for potential cutworm control is present with the addition of diazinon.

Sprayed vs. Injected Study

ANOVA revealed the interaction between halosulfuron and diazinon was significant (P = 0.0616) (Table 2). ANOVA revealed the interaction between halosulfuron and application type was significant (P = 0.0528) (Table 2). No differences were observed between injected and sprayed treatments (Table 2), therefore all treatments were sprayed in the subsequent study. $LSD_{0.05}$ between any two individual treatment means was equal to 2. The greatest amount of yellow nutsedge control was observed when plots were sprayed with the lowest level of halosulfuron (39 g ai/ha) combined with the highest level of diazinon (2.24 kg ai/ha). This treatment was able to control the nutsedge population by 93%, which is almost double the control observed with the lowest level of halosulfuron sprayed alone (42% control) (Table 2).

Sprayed Study

ANOVA revealed the interaction between halosulfuron and diazinon was not significant (P = 0.3863; Table 3). The $LSD_{0.05}$ between any two individual treatment means was equal to 2.00. No differences were observed among treatments (Table 3). The greatest amount of yellow nutsedge control was observed among the lowest level of halosulfuron (21 g ai/ha) combined with the middle rate of diazinon (280 g ai/ha). This treatment was able to control the nutsedge population by 83% (Table 3).

A synergistic effect was observed in the first field study, but not in the second. Rates were lowered considerably in the second study to agree with industry standards. Irregular rain and an inconsistent nutsedge population (1.7 plants/plot) may have contributed to the results in both studies. Some nutsedge control was observed in both studies, but the plastic mulch was rendered useless for use with a second crop. Continuing research is required in order to fully investigate the interaction between halosulfuron and diazinon observed in the greenhouse.

LITERATURE CITED

Biediger, D. L., P. A. Baumann, D. N. Weaver, J. M. Chandler, and M. G. Merkle. 1992. Interactions between primisulfuron and selected soil-applied insecticides in corn (*Zea mays*). Weed Technol. 6:807-812.

Brandenberger, L. P., R. E. Talbert, R. P. Wiedenfeld, J. W. Shrefler, C. L. Webber III, and M. S. Malik. 2005. Effects of halosulfuron on weed control in commercial honeydew crops. Weed Technol. 19:346-350.

Chase, C. A., T. R. Sinclair, D. G. Shilling, J. P. Gilreath, and S. J. Locascio. 1998. Light effects on rhizome morphogenesis in nutsedges (*Cyperus* spp): implications for control by soil solarization. Weed Sci. 47:467-472.

Christopher, J. T., C. Preston, and S. Powles. 1994. Malathion antagonizes metabolism-based chlorsulfuron resistance in *Lolium rigidum*. Pesticide Biochem. and Physiol. 49:172-182.

Dorst, D. C. and J. D. Doll. 1980. The allelopathic effect of yellow nutsedge (*Cyperus esculentus*) on corn (*Zea mays*) and soybeans (*Glycine max*). Weed Sci. 28:229-233.

Earl, H. J., J. A. Ferrell, W. K. Vencill, M. W. van Iersel, M. A. Czarnota. 2004. Effects of three herbicides on whole-plant carbon fixation and water use by yellow nutsedge (*Cyperus esculentus*). Weed Sci. 52:213-216.

Fennimore, S. A. and S. J. Richard. 1999. Screening of Low Rate Herbicides in Vegetable Crops. Moscow, ID: West. Soc. Weed Sci. Res. Prog. Rep. Pp. 44-46.

Ferrel, J. A., H. J. Earl, and W. K. Vencill. 2004. Duration of yellow nutsedge (*Cyperus esculentus*) competitiveness after herbicide treatment. Weed Sci. 52:24-27.

Holm, L. G., D. C. Plunknett, J.V. Pancho, and J.P. Herberger. 1977. The World's Worst Weeds: Distribution and Biology. Honolulu, HI: Univ. Press of Hawaii. Pp. 125-133.

Johnson III, W. C. and B. G. Mullinix Jr. 2006. Yellow nutsedge (*Cyperus esculentus*) control with metam-sodium in transplanted cantaloupe (*Cucmis melo*). Crop Protection 26:867-871.

Kansouh, A. S. H. and T. L. Hopkins. 1968. Diazinon absorption, translocation, and metabolism in bean plants. J. Agr. Food Chem. 16:446-450.

Keeley, P. E. 1987. Interference of interaction of purple nutsedge and yellow nutsedges (*Cyperus rotundus* and *C. esculentus*) in crops. Weed Technol. 1:74-81.

Kemble, J. M., M. G. Patterson, and J. W. Everest. 2004. Nutsedge control in commercial vegetables. Alabama Cooperative Extension System Alabama A&M and Auburn Universities. ANR-1073.

Kidd, H. and D. R. James (eds.) 1991. The Agrochemicals Handbook. 3rd ed. Unwin Brothers Limited, Old Woking, Surrey, U.K.

Minton, B., M. Matocha, and S. Senseman. 2008. The influence of malathion on trifloxysulfuron absorption and translocation in cotton. Cotton Sci. 12:48-52.

Monks, D. W., K. M. Jennings, W.E. Mitchem. 2008. Chemical weed control in vegetable crops. P. 255. In: Vegetable Crop Handbook for Southeastern United States.

Nelson, K. A. and K. A. Renner. 2002. Yellow nutsedge (*Cyperus esculentus*) control and tuber production with glyphosate and ALS-Inhibiting herbicides. Weed Technol. 16:512-519.

Phatak, S. C., M. B. Callaway, and C. S. Vavrina. 1987. Biological control and its integration in weed management systems of purple and yellow nutsedge (*Cyperus rotundus* and *C. esculentus*). Weed Technol. 1:84-91.

Porpiglia, P. J., G. R. Gillespie, and M. D. Johnson. 1990. Enhanced CGA-136872 activity in combination with insecticides. Proc. of the Weed Sci. Soc. of Amer. 30:6.

Rahman, A., T. K. James. 1993. Enhanced activity of nicosulfuron in combination with soil-applied insecticides in corn (*Zea mays*). Weed Technol. 7:824-829.

Ransom, C. V., C. A. Rice, and C. C. Shock. 2009. Yellow nutsedge (*Cyperus esculentus*) growth and reproduction in response to nitrogen and irrigation. Weed Sci. 57:21-25.

Tumbleson, M. E. and T. Kommedahl. 1961. Reproductive potential of *Cyperus esculentus* by tubers. Weeds 9:646-653.

Walgenback, J., M. Abney, G. Kennedy, P. Smith, R. Bessin, A. Sparks, D. Riley, M. Layton, F. Hale. 2008. Insect control for commercial vegetables. P.155. In: Vegetable Crop Handbook for Southeastern United States.

Wang, G., M. E. McGiffen Jr., E. J. Ogbuchiekwe. 2008. Crop rotation effects on *Cyperus rotundus* and *C. esculentus* population dynamics in southern California vegetable production. Weed Res. 48, 420-428.

Webster, T. M. 2005. Mulch type affects growth and tuber production of yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*Cyperus rotundus*). Weed Sci. 53:834-838.

Webster, T. M., T. Grey, J. W. Davis, and A. S. Culpepper. 2008. Glyphosate hinders purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*Cyperus esculentus*) tuber production. Weed Sci. 56:735-742.

Table 1. Effects of halosulfuron (PRE) and diazinon on control of yellow nutsedge; PSRC greenhouse Auburn, AL.).

Source of Variation:	Probability
Halosulfuron	<0.0001
Diazinon	0.0044
Halosulfuron x Diazinon	<0.0001

Overall Treatment Effects

Halosulfuron (g ai/ha)	Diazinon (g ai/ha)					Means
	0	**140**	**280**	**420**	**560**	$\overline{X}$
	%					%
0	0	70	52	68	67	49 C
14	68	87	96	81	89	84 B
21	94	78	92	78	93	87 B
28	96	96	73	76	87	86 B
35	95	98	98	100	96	98 A
$\overline{X}$	68 B*	86 A	82 A	81 A	86 A	

*Main effects followed by the same letter are not different according to Waller Duncan Multiple Rage Test ($P \leq 0.05$). $LSD_{0.05}$ between any two individual treatment means is 2.

Table 2. Effects of halosulfuron (PRE), diazinon rate, and sprayed vs. injected on of yellow nutsedge control on plastic mulch; Tallassee, Al. September 2008.

Source of Variation:	**Probability**
Halosulfuron	0.3026
Diazinon	0.4913
Halosulfuron x Diazinon	0.0616
Application Type	0.3951
Halosulfuron x Application	0.0528
Diazinon x Application	0.4424
Halosulfuron x Diazinon x Application	0.9141

Halosulfuron	**Application**	**Diazinon**		
		0	**1.12**	**2.24**
		----------------------------------	**%**	----------------------------------
39	Injected	66	11	72
53	Injected	41	54	19
$\overline{X}$		53 AB*	32 AB	45 AB
39	Sprayed	42	62	93
53	Sprayed	74	53	74
$\overline{X}$		58 A	57 A	83 A
0	Nontreated	0	--	--

*Main effects followed by the same letter are not different according to Waller Duncan Multiple Range Test ($P \leq 0.05$). $LSD_{0.05}$ between any two individual treatment means is 2.

Table 3. Effects of halosulfuron (PRE) and diazinon rate on of yellow nutsedge control on plastic mulch; Tallassee, Al. July 2009.

Source of Variation:	Probability
Halosulfuron	0.6415
Diazinon	0.5723
Halosulfuron x Diazinon	0.3863

Overall Treatment Effects

Halosulfuron (g ai/ha)	Diazinon (g ai/ha)				Means
	0	**140**	**280**	**420**	$\overline{X}$
	%				%
0	0	--	--	--	0 B
21	60	43	83	53	60 A
28	68	80	50	82	70 A
35	44	74	80	66	66 A
$\overline{X}$	43 A*	66 A	71 A	67 A	

*Main effects followed by the same letter are not different according to Waller Duncan Multiple Range Test ($P \leq 0.05$). $LSD_{0.05}$ between any two individual treatment means is 2.

CHAPTER 3

EVALUATION OF HALOSULFURON AND DIAZINON COMBINATIONS FOR YELLOW NUTSEDGE CONTROL IN TOMATO PRODUCTION

Matthew C. Lollar, Wheeler G. Foshee III, Glenn R. Wehtje, and Charles H. Gilliam

Abstract: Field studies were conducted in 2009 at Auburn University's Wiregrass Research and Extension Center (WREC) in Headland, Alabama. Nine treatments were included. The first four were halosulfuron at 35 g ai/ha in combination with diazinon at either 560, 420, 280, or 140 g ai/ha. The fifth treatment was halosulfuron at 28 g ai/ha in combination with diazinon at 140 g ai/ha. The sixth and seventh treatments were halosulfuron at 21 g ai/ha in combination with diazinon at either 560 or 280 g ai/ha. The eighth treatment was halosulfuron at 14 g ai/ha and diazinon at 280 g ai/ha. All treatments were sprayed due to results from previous research. Approximately 30 days after application (DAA), when the nutsedge population was prominent, emergence data was collected in the first study and weed biomass was collected in the second study. The most effective treatment, in the first study was the highest level of halosulfuron combined with the highest level of diazinon. The most effective treatment, in the second study, was a low level of halosulfuron combined with the highest level of diazinon. Compared to the non-treated control, nutsedge emergence was controlled by 82% with this treatment.

Nomenclature: halosulfuron; diazinon; yellow nutsedge (*Cyperus esculentus*); sulfonylurea; PRE; POST; organophosphate; polyethylene

Abbreviations: SU, sulfonylurea; PRE, preemergence; POST, postemergence; DAA, days after application; CRD, completely randomized design

INTRODUCTION

Croplands in countries worldwide are populated by nutsedge classifying it as one of the worst weeds on the planet (Holm et al. 1977; Earl et al., 2004). Plentiful vegetative reproduction is prevalent in yellow nutsedge making it a persistent weed problem. Nutsedge has the ability to survive harsh conditions and thrive under good conditions due to prolific vegetative reproduction (Tumbleson and Kommedahl, 1961; Wang et al., 2008). Their tubers are able to remain dormant through the winter then produce shoots in following growing seasons (Ransom et al., 2009). Documented cases have shown that yellow nutsedge can reduce corn and soybean yields by 79 and 87%, respectively (Earl et al., 2004). Yellow nutsedge has also been reported to contain allelopathic compounds (Dorst and Doll 1980; Ferrel et al., 2004) and can serve as an alternative host for plant pathogens (Phatak et al., 1987; Ferrel et al., 2004). Such evidence validates the advantages of nutsedge control early in the season to reduce competition for water, light, and nutrients (Keeley 1987; Earl et al., 2004). In addition, any tillage before planting multiplies the problem by spreading tubers (Kemble et al., 2004). A combination of cultural and chemical control is required for adequate nutsedge management and only a few herbicides are registered in vegetable crops for nutsedge control (Kemble et al., 2004).

Halosulfuron is a systemic sulfonylurea (SU) herbicide that is registered for corn, vegetable crops, and turfgrass. Yellow nutsedge had to be controlled by a variety of different herbicides before the introduction of halosulfuron. Preemergence (PRE) and postemergence (POST) activity on yellow nutsedge have been observed with halosulfuron. The Food Quality Protection Act has cancelled several herbicides creating a demand for safe alternatives such as halosulfuron (Fennimore and Richard 1999; Brandenberger et al., 2005). Nelson and Renner (2002) observed an 80% reduction in both nutsedge tuber density and fresh weight when halosulfuron was POST applied at a rate of 35 g/ha. The registered rate for halosulfuron on tomatoes is 27 to 54 g ai/ha (Monks et al., 2008).

Diazinon is an organophosphate insecticide that was first manufactured in 1952. Diazinon is an insecticide and acaricide available for a wide range of crops including fruit trees, corn, and tomatoes. It has contact, stomach, and respiratory activity against sucking and chewing insects and mites (Kidd and James, 1991). Studies have shown that diazinon is absorbed and translocated within plants (Kansouh and Hopkins, 1968). The registered application rate for diazinon on tomatoes is 280 g ai/ha (Walgenback et al., 2008).

Organophosphates, such as diazinon, can be used to increase the efficacy of sulfonylurea herbicides while retaining selectivity in certain crops. Mortality for *Lolium rigidum* was increased when the organophosphate insecticide, malathion, was tank mixed with the sulfonylurea, chlorsulfuron (Christopher et al., 1994). Minton et al. (2008) observed greater translocation of trifloxysulfuron in cotton plants (*Gossypium hirsutum*) when it was mixed with malathion. Greater phytotoxicity was also observed compared to trifloxysulfuron alone (Minton et al. 2008). Rahman and James (1993) observed a higher damage percentage in corn (*Zea mays*) when the organophosphate terbufos was applied prior to the application of the sulfonylurea nicosulfuron. Corn injury has also been noted with mixtures of the sulfonylurea primisulfuron and select organophosphates (Biediger et al., 1992). These studies suggest that the synergistic interaction occurs because the insecticide increases the uptake of the sulfonylurea herbicide and decreases plant metabolism (Porpiglia et al., 1990).Tomato and bell pepper weed control contributes heavily to production costs, amounting to about 10% of total operating costs for these crops (IFAS-UF 1999).

Polyethylene is used in the production of tomatoes and peppers and has the potential to aid in nutsedge suppression (Chase et al. 1998; Webster 2005). It cannot act alone due to the fact that nutsedge can puncture and emerge through the plastic and successfully compete with other crops (Chase et al. 1998; Johnson and Mullinix, 2006). Nutsedge's desiccation of plastic mulch hinders the ability of growers to use the mulch for multiple crops, further elevating the cost of production (Webster et al., 2008).

MATERIALS AND METHODS

Two field studies were conducted in 2009 at Auburn University's Wiregrass Research and Extension Center (WREC) on a Dothan sandy loam soil (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) (USDA series description) with a pH of 6.0. The soil was prepared and shaped into nine parallel beds. Nine treatments were included. The first four were halosulfuron at 35 g ai/ha in combination with diazinon at either 560, 420, 280, or 140 g ai/ha. The fifth treatment was halosulfuron at 28 g ai/ha in combination with diazinon at 140 g ai/ha. The sixth and seventh treatments were halosulfuron at 21 g ai/ha in combination with diazinon at either 560 or 280 g ai/ha. The eighth treatment was halosulfuron at 14 g ai/ha and diazinon at 280 g ai/ha. A complete randomized block design was observed. A field with a heavy infestation of yellow nutsedge was chosen. Individual plots were 4.6 m long with a 3.0 m alley at both ends and consisted of preformed beds with drip tape. Treatments were applied with a CO_2 back-pack sprayer set to deliver 280 liters per hectare (L/ha). The sprayer was equipped with two 11005 spray nozzles spaced 45 cm apart on the boom. Polyethylene mulch was applied to the second study while the first study was left bare ground. Tomato transplants (1st Study 'Bella Rosa'; 2nd Study 'Polbig') were planted on 46 cm spacing and were grown and maintained according to commercial tomato practices. Ten tomato transplants were planted per plot in each study. About

30 days after application (DAA), nutsedge emergence counts were made in a 0.30 m section of each plot in the first study. In the second study, yellow nutsedge biomass was collected for a 1 m section from each plot about 30 DAA.

Statistical analysis was conducted using a general linear model with the PROC GLM procedure of SAS Version 9.1 (SAS Institute, Cary, NC) for emergence data (1st Study) and fresh weight data (2nd Study).

RESULTS AND DISCUSSION

Bareground

The interaction between halosulfuron and diazinon was not significant (P = 0.9207) (Table 1). $LSD_{0.05}$ between any two individual treatment means was equal to 2. All treatments had higher percent control than the nontreated control (Table 1). However all of the selected combinations were similar (Table 1). A large population of nutsedge, 450 plants per square meter, was observed and caused crop failure of the tomatoes, therefore no yield data was obtained.

This bareground study with a high infestation of yellow nutsedge revealed that none of the treatment combinations gave adequate control. Therefore, the follow-up study was conducted on black plastic mulch in a similar plot.

Plastic Mulch

The interaction between halosulfuron and diazinon was not significant (P = 0.6310) (Table 2). Halosulfuron did effect percent control of yellow nutsedge (P = 0.0006) (Table 2). $LSD_{0.05}$ between any two individual treatment means was equal to 2. The greatest amount of yellow nutsedge control was observed among a low level of halosulfuron (21 g ai/ha) combined with the highest level of diazinon (560 g ai/ha). Compared to the non-treated control, nutsedge emergence was controlled by 82% with this treatment (Table 2). Tomato yields were not collected due to record rainfall amounts received in the area and subsequently, crop failure occurred.

An overwhelming nutsedge population was present in the first study (around 450 plants per square meter); therefore tomatoes were grown on plastic mulch in the subsequent study. Although the main effect of halosulfuron was significant in the plastic mulch study ($P = 0.0006$), the interaction was not ($P = 0.6310$) (Table 2). The low rate of halosulfuron (21 g ai/ha) combined with 560 g ai/ha of diazinon gave 82% control. Although this was not different from other combinations, this is noteworthy since it approaches 90% control which is the minimum percent control recognized by weed scientists (Webster 2005). Continuing research is required to fully evaluate the interaction between these two combinations.

LITERATURE CITED

Biediger, D. L., P. A. Baumann, D. N. Weaver, J. M. Chandler, and M. G. Merkle. 1992. Interactions between primisulfuron and selected soil-applied insecticides in corn (*Zea mays*). Weed Technol. 6:807-812.

Brandenberger, L. P., R. E. Talbert, R. P. Wiedenfeld, J. W. Shrefler, C. L. Webber III, and M. S. Malik. 2005. Effects of halosulfuron on weed control in commercial honeydew crops. Weed Technol. 19:346-350.

Chase, C. A., T. R. Sinclair, D. G. Shilling, J. P. Gilreath, and S. J. Locascio. 1998. Light effects on rhizome morphogenesis in nutsedges (*Cyperus* spp): implications for control by soil solarization. Weed Sci. 47:467-472.

Christopher, J. T., C. Preston, and S. Powles. 1994. Malathion antagonizes metabolism-based chlorsulfuron resistance in *Lolium rigidum*. Pesticide Biochem. and Physiol. 49:172-182.

Earl, H. J., J. A. Ferrell, W. K. Vencill, M. W. van Iersel, M. A. Czarnota. 2004. Effects of three herbicides on whole-plant carbon fixation and water use by yellow nutsedge (*Cyperus esculentus*). Weed Sci. 52:213-216.

Fennimore, S. A. and S. J. Richard. 1999. Screening of Low Rate Herbicides in Vegetable Crops. Moscow, ID: West. Soc. Weed Sci. Res. Prog. Rep. Pp. 44-46.

Holm, L. G., D. C. Plunknett, J.V. Pancho, and J.P. Herberger. 1977. The World's Worst Weeds: Distribution and Biology. Honolulu, HI: Univ. Press of Hawaii. Pp. 125-133.

[IFAS-UF] Institute of Food and Agricultural Sciences, University of Florida. 1999. Cost of Production for Florida Vegetables, 1997-98: Web page: http://www.agbuscenter.ifas.ufl.edu.

Johnson III, W. C. and B. G. Mullinix Jr. 2006. Yellow nutsedge (*Cyperus esculentus*) control with metam-sodium in transplanted cantaloupe (*Cucmis melo*). Crop Protection 26:867-871.

Kansouh, A. S. H. and T. L. Hopkins. 1968. Diazinon absorption, translocation, and metabolism in bean plants. J. Agr. Food Chem. 16:446-450.

Keeley, P. E. 1987. Interference of interaction of purple nutsedge and yellow nutsedges (*Cyperus rotundus* and *C. esculentus*) in crops. Weed Technol. 1:74-81.

Kemble, J. M., M. G. Patterson, and J. W. Everest. 2004. Nutsedge control in commercial vegetables. Alabama Cooperative Extension System Alabama A&M and Auburn Universities. ANR-1073.

Kidd, H. and D. R. James (eds.) 1991. The Agrochemicals Handbook. 3rd ed. Unwin Brothers Limited, Old Woking, Surrey, U.K.

Minton, B., M. Matocha, and S. Senseman. 2008. The influence of malathion on trifloxysulfuron absorption and translocation in cotton. Cotton Sci. 12:48-52.

Monks, D. W., K. M. Jennings, W.E. Mitchem. 2008. Chemical weed control in vegetable crops. P. 255. In: Vegetable Crop Handbook for Southeastern United States.

Nelson, K. A. and K. A. Renner. 2002. Yellow nutsedge (*Cyperus esculentus*) control and tuber production with glyphosate and ALS-Inhibiting herbicides. Weed Technol. 16:512-519.

Porpiglia, P. J., G. R. Gillespie, and M. D. Johnson. 1990. Enhanced CGA-136872 activity in combination with insecticides. Proc. of the Weed Sci. Soc. of Amer. 30:6.

Rahman, A., T. K. James. 1993. Enhanced activity of nicosulfuron in combination with soil-applied insecticides in corn (*Zea mays*). Weed Technol. 7:824-829.

Ransom, C. V., C. A. Rice, and C. C. Shock. 2009. Yellow nutsedge (*Cyperus esculentus*) growth and reproduction in response to nitrogen and irrigation. Weed Sci. 57:21-25.

Tumbleson, M. E. and T. Kommedahl. 1961. Reproductive potential of *Cyperus esculentus* by tubers. Weeds 9:646-653.

Walgenback, J., M. Abney, G. Kennedy, P. Smith, R. Bessin, A. Sparks, D. Riley, M. Layton, F. Hale. 2008. Insect control for commercial vegetables. P.155. In: Vegetable Crop Handbook for Southeastern United States.

Wang, G., M. E. McGiffen Jr., E. J. Ogbuchiekwe. 2008. Crop rotation effects on *Cyperus rotundus* and *C. esculentus* population dynamics in southern California vegetable production. Weed Res. 48, 420-428.

Webster, T. M. 2005. Mulch type affects growth and tuber production of yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*Cyperus rotundus*). Weed Sci. 53:834-838.

Webster, T. M., T. Grey, J. W. Davis, and A. S. Culpepper. 2008. Glyphosate hinders purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*Cyperus esculentus*) tuber production. Weed Sci. 56:735-742.

Table 1. Effects of halosulfuron (PRE) and diazinon rate on yellow nutsedge control on bareground; Headland, Al.

Source of Variation:	Probability
Halosulfuron	0.8712
Diazinon	0.9205
Halosulfuron x Diazinon	0.9207

Overall Treatment Effects

Halosulfuron (g ai/ha)	Diazinon (g ai/ha)	% Control
35	560	**37a***
35	420	**33a**
35	280	**29a**
35	140	**33a**
28	140	**21a**
21	560	**35a**
21	280	**30a**
14	280	**26a**
0	0	**0b**

*Main effects followed by the same letter are not different according to Waller Duncan Multiple Range Test ($P \leq 0.05$). The $LSD_{0.05}$ between any two individual treatment means is 2.

Table 2. Effects of halosulfuron (PRE) and diazinon rate on yellow nutsedge control on plastic mulch; Headland, Al.

Source of Variation:	Probability
Halosulfuron	0.0006
Diazinon	0.5927
Halosulfuron x Diazinon	0.6310

Overall Treatment Effects

Halosulfuron (g ai/ha)	Diazinon (g ai/ha)	% Control
35	560	**61ab***
35	420	**52ab**
35	280	**51ab**
35	140	**59ab**
28	140	**34bc**
21	560	**82a**
21	280	**60ab**
14	280	**44b**
0	0	**0c**

*Main effects followed by the same letter are not different according to Waller Duncan Multiple Range Test ($P \leq 0.05$). The $LSD_{0.05}$ between any two individual treatment means is 2.

CHAPTER 4

EVALUATION OF TRIFLOXYSULFURON AND DIAZINON COMBINATIONS FOR THE MANAGEMENT OF YELLOW NUTSEDGE

Matthew C. Lollar, Wheeler G. Foshee III, Glenn R. Wehtje, and Charles H. Gilliam

Abstract: Greenhouse studies were conducted in 2009 at Auburn University's Plant Science Research Center to determine effects of trifloxysulfuron and diazinon combinations for yellow nutsedge control. In the first study, treatments consisted of a factorial arrangement of 5 rates of trifloxysulfuron (0, 2.69, 5.27, 7.96, and 10.54 g a.i./ha) and 5 rates of diazinon (0, 140, 280, 420, and 560 g a.i./ha); yielding 25 separate treatments. A completely randomized design (CRD) was observed. In the second study, treatments consisted of a factorial arrangement of 5 rates of trifloxysulfuron (0, 1.68, 2.13, 2.91, and 3.92 g a.i./ha) and 5 rates of diazinon (0, 140, 280, 420, and 560 g a.i./ha); yielding 25 separate treatments. A CRD was observed. The first study yielded no nutsedge emergence so trifloxysulfuron rates were reduced in the second study. Approximately 30 days after application (DAA), when nutsedge emergence was abundant, weed biomass was collected for each cup in the second study. In the second study, ANOVA revealed the main effect of trifloxysulfuron was significant ($P < 0.0001$) as well as the interaction between trifloxysulfuron and diazinon ($P = 0.0034$). Therefore the two pesticides are synergistic with respect to their ability to control yellow nutsedge.

Nomenclature: trifloxysulfuron; diazinon; yellow nutsedge (*Cyperus esculentus*); sulfonylurea; PRE; POST; organophosphate

Abbreviations: SU, sulfonylurea; PRE, preemergence; POST, postemergence; DAA, days after application; CRD, completely randomized design

INTRODUCTION

Croplands in countries worldwide are populated by nutsedge classifying it as one of the worst weeds on the planet (Holm et al. 1977; Earl et al., 2004). Plentiful vegetative reproduction is prevalent in yellow nutsedge making it a persistent weed problem. Nutsedge has the ability to survive harsh conditions and thrive under good conditions due to prolific vegetative reproduction (Tumbleson and Kommedahl, 1961; Wang et al., 2008). Their tubers are able to remain dormant through the winter then produce shoots in following growing seasons (Ransom et al., 2009). Documented cases have shown that yellow nutsedge can reduce corn and soybean yields by 79 and 87%, respectively. Yellow nutsedge has also been found to contain allelopathic compounds (Dorst and Doll 1980; Ferrel et al., 2004) and can serve as an alternative host for plant pathogens (Phatak et al., 1987; Ferrel et al., 2004). Such evidence alludes to the advantages of nutsedge control early in the season to reduce competition for water, light, and nutrients (Keeley 1987; Earl et al., 2004). In addition, cultural practices such as primary tillage before planting multiply the problem by spreading the tubers (Kemble et al., 2004). A combination of cultural and chemical control is required for adequate nutsedge management and only a few herbicides are registered in vegetable crops for nutsedge control, which serves as a major problem (Kemble et al., 2004).

Trifloxysulfuron is a systemic SU herbicide registered in tomatoes, cotton, and turfgrass (Minton et al., 2008). It offers postemergence (POST) control of yellow nutsedge, a few grasses, and some broadleaf weeds (Bangarwa et al., 2009). The registered application rate for trifloxysulfuron on tomatoes is 10.5 g ai/ha (Monks et al., 2008).

Diazinon is an organophosphate insecticide that was first manufactured in 1952. Diazinon is an insecticide and acaricide available for a wide range of crops including fruit trees, corn, and tomatoes. It has contact, stomach, and respiratory activity against sucking and chewing insects and mites (Kidd and James, 1991). Studies have shown that diazinon is absorbed and translocated within plants (Kansouh and Hopkins, 1968). The registered application rate for diazinon on tomatoes is 280 g ai/ha (Walgenback et al., 2008).

Organophosphates, such as diazinon, can be used to increase the efficacy of sulfonylurea herbicides while retaining selectivity in certain crops. Mortality for *Lolium rigidum* was increased when the organophosphate insecticide, malathion, was tank mixed with the sulfonylurea, chlorsulfuron (Christopher et al., 1994). Minton et al. (2008) observed greater translocation of trifloxysulfuron in cotton plants (*Gossypium hirsutum*) when it was mixed with malathion. Greater phytotoxicity was also observed compared to trifloxysulfuron alone (Minton et al. 2008). Rahman and James (1993) observed a higher damage percentage in corn (*Zea mays*) when the organophosphate terbufos was applied prior to the application of the sulfonylurea nicosulfuron. Corn injury has also been noted with mixtures of the sulfonylurea primisulfuron and select organophosphates (Biediger et al., 1992). These studies suggest that the synergistic interaction occurs because the insecticide increases the uptake of the sulfonylurea herbicide and decreases plant metabolism (Porpiglia et al., 1990).Tomato and bell pepper weed control contributes heavily to production costs, amounting to about 10% of total operating costs for these crops (IFAS-UF 1999).

The objective of this study was to evaluate PRE-applied trifloxysulfuron and diazinon tank mixtures within a controlled environment in order to determine respectable rates for field application.

MATERIALS AND METHODS

Greenhouse studies were conducted in 2009 at Auburn University's Plant Science Research Center (PSRC). The first study was conducted in July 2009 and the study was repeated in August 2009. Styrofoam cups (400 ml) were filled with a Marvyn sandy loam soil (fine-loamy, kaolinitic, thermic type Kanhapludults) (USDA series description) excavated from Auburn University's E. V. Smith Research Center (EVS). Three pre-germinated yellow nutsedge tubers were planted at a depth of 2.5 cm in each cup. In the first study, treatments consisted of a factorial arrangement of 5 rates of trifloxysulfuron (0, 2.69, 5.27, 7.96, and 10.54 g a.i./ha) and 5 rates of diazinon (0, 140, 280, 420, and 560 g a.i./ha); yielding 25 separate treatments. Each treatment was replicated 6 times. A completely randomized design was observed. In the second study, treatments consisted of a factorial arrangement of 5 rates of trifloxysulfuron (0, 1.68, 2.13, 2.91, and 3.92 g a.i./ha) and 5 rates of diazinon (0, 140, 280, 420, and 560 g a.i./ha); yielding 25 separate treatments. Each treatment was replicated 6 times. A completely randomized design was observed. Treatments were applied with a compressed air powered spray booth manufactured by DeVries Manufacturing (Hollandale, MN). The spray booth was equipped with a 8002VS nozzle which rode along a stainless steel shaft and delivered 280 liters per hectare (L/ha). Approximately 30 days after application (DAA) when nutsedge was fully emerged, nutsedge biomass was taken for each cup.

Statistical analysis was conducted for fresh weight data using a general linear model with the PROC GLM procedure of SAS Version 9.1 (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

In the first study, ANOVA revealed the main effects of trifloxysulfuron and diazinon were significant ($P < 0.0001$) as well as the interaction between trifloxysulfuron and diazinon (P

< 0.0001) (Table 1). This indicates that the two pesticides may be synergistic with respect to their ability to control yellow nutsedge. $LSD_{0.05}$ between any two individual treatment means was 2. All treatments, except for one (2.69 g ai/ha trifloxysulfuron + 140 g ai/ha diazinon) controlled emergence of yellow nutsedge by 100% compared to the non-treated control (Table 1). Therefore, trifloxysulfuron rates were reduced in the subsequent study.

In the second study, ANOVA revealed the main effect of trifloxysulfuron was significant ($P < 0.0001$) as well as the interaction between trifloxysulfuron and diazinon ($P = 0.0034$) (Table 2). Therefore the two pesticides were synergistic with respect to their ability to control yellow nutsedge. $LSD_{0.05}$ between any two individual treatment means was 2. The highest rate of trifloxysulfuron (3.92 g ai/ha) combined with the highest rate of diazinon (560 g ai/ha) was able to control emergence by 88%, compared to the non-treated control (Table 2). Although this treatment contained the highest rates of trifloxysulfuron and diazinon, the trifloxysulfuron level was low compared to labeled rates.

Trifloxysulfuron is currently not labeled for soil application due to its low level of soil activity. However, a synergism between trifloxysulfuron and diazinon was observed in the greenhouse, suggesting that subsequent field research should be conducted. The estimated cost to-date for trifloxysulfuron at the recommended rate of 10.51 g ai/ha is $45.79. The cost per hectare for diazinon at the recommended rate of 560 g ai/ha is $13.91/ha. Therefore, the total cost per hectare for the best performing tank mixture (3.92 g ai/ha + 560 g ai/ha diazinon) would be $17.17/ha trifloxysulfuron + $13.91/ha, which is equal to $31.08/ha. This is a total savings of $14.71 compared to the recommended rate of trifloxysulfuron (10.51 g ai/ha) applied alone, which represents a total savings of over 30 percent for producers. Also, the potential benefit of cutworm control is present with the addition of diazinon.

LITERATURE CITED

Bangarwa, S. K., J. K. Norsworthy, and E. E. Gbur. 2009. Integration of a brassicaceae cover crop with herbicides in plasticulture tomato. Weed Technol. 23:280-286.

Biediger, D. L., P. A. Baumann, D. N. Weaver, J. M. Chandler, and M. G. Merkle. 1992. Interactions between primisulfuron and selected soil-applied insecticides in corn (*Zea mays*). Weed Technol. 6:807-812.

Christopher, J. T., C. Preston, and S. Powles. 1994. Malathion antagonizes metabolism-based chlorsulfuron resistance in *Lolium rigidum*. Pesticide Biochem. and Physiol. 49:172-182.

Dorst, D. C. and J. D. Doll. 1980. The allelopathic effect of yellow nutsedge (*Cyperus esculentus*) on corn (*Zea mays*) and soybeans (*Glycine max*). Weed Sci. 28:229-233.

Earl, H. J., J. A. Ferrell, W. K. Vencill, M. W. van Iersel, M. A. Czarnota. 2004. Effects of three herbicides on whole-plant carbon fixation and water use by yellow nutsedge (*Cyperus esculentus*). Weed Sci. 52:213-216.

Holm, L. G., D. C. Plunknett, J.V. Pancho, and J.P. Herberger. 1977. The World's Worst Weeds: Distribution and Biology. Honolulu, HI: Univ. Press of Hawaii. Pp. 125-133.

Kansouh, A. S. H. and T. L. Hopkins. 1968. Diazinon absorption, translocation, and metabolism in bean plants. J. Agr. Food Chem. 16:446-450.

Keeley, P. E. 1987. Interference of interaction of purple nutsedge and yellow nutsedges (*Cyperus rotundus* and *C. esculentus*) in crops. Weed Technol. 1:74-81.

Kemble, J. M., M. G. Patterson, and J. W. Everest. 2004. Nutsedge control in commercial vegetables. Alabama Cooperative Extension System Alabama A&M and Auburn Universities. ANR-1073.

Kidd, H. and D. R. James (eds.) 1991. The Agrochemicals Handbook. 3rd ed. Unwin Brothers Limited, Old Woking, Surrey, U.K.

Minton, B., M. Matocha, and S. Senseman. 2008. The influence of malathion on trifloxysulfuron absorption and translocation in cotton. Cotton Sci. 12:48-52.

Monks, D. W., K. M. Jennings, W.E. Mitchem. 2008. Chemical weed control in vegetable crops. P. 255. In: Vegetable Crop Handbook for Southeastern United States.

Phatak, S. C., M. B. Callaway, and C. S. Vavrina. 1987. Biological control and its integration in weed management systems of purple and yellow nutsedge (*Cyperus rotundus* and *C. esculentus*). Weed Technol. 1:84-91.

Porpiglia, P. J., G. R. Gillespie, and M. D. Johnson. 1990. Enhanced CGA-136872 activity in combination with insecticides. Proc. of the Weed Sci. Soc. of Amer. 30:6.

Rahman, A., T. K. James. 1993. Enhanced activity of nicosulfuron in combination with soil-applied insecticides in corn (*Zea mays*). Weed Technol. 7:824-829.

Ransom, C. V., C. A. Rice, and C. C. Shock. 2009. Yellow nutsedge (*Cyperus esculentus*) growth and reproduction in response to nitrogen and irrigation. Weed Sci. 57:21-25.

Tumbleson, M. E. and T. Kommedahl. 1961. Reproductive potential of *Cyperus esculentus* by tubers. Weeds 9:646-653.

Walgenback, J., M. Abney, G. Kennedy, P. Smith, R. Bessin, A. Sparks, D. Riley, M. Layton, F. Hale. 2008. Insect control for commercial vegetables. P.155. In: Vegetable Crop Handbook for Southeastern United States.

Wang, G., M. E. McGiffen Jr., E. J. Ogbuchiekwe. 2008. Crop rotation effects on *Cyperus rotundus* and *C. esculentus* population dynamics in southern California vegetable production. Weed Res. 48, 420-428.

Table 1. Effects of trifloxysulfuron (PRE) and diazinon on yellow nutsedge control; PSRC greenhouse Auburn, AL (1st Study).

Source of Variation:	Probability
Halosulfuron	<0.0001
Diazinon	<0.0001
Halosulfuron x Diazinon	<0.0001

Overall Treatment Effects

Halosulfuron (g ai/ha)	Diazinon (g ai/ha)					Means
	0	**140**	**280**	**420**	**560**	$\bar{X}$
	---------------------------		%		----------------------------	---- % ----
0	0	--	--	--	--	0 B
2.69	100	99	100	100	100	100 A
5.27	100	100	100	100	100	100 A
7.96	100	100	100	100	100	100 A
10.54	100	100	100	100	100	100 A
$\bar{X}$	83 B*	100 A	100 A	100 A	100 A	

*Main effects followed by the same letter are not different according to Waller Duncan Multiple Range Test ($P \leq 0.05$). $LSD_{0.05}$ between any two individual treatment means is 2.

Table 2. Effects of trifloxysulfuron (PRE) and diazinon on yellow nutsedge control; PSRC greenhouse Auburn, AL (2nd Study).

Source of Variation:	Probability
Halosulfuron	<0.0001
Diazinon	0.6845
Halosulfuron x Diazinon	0.0034

Overall Treatment Effects

Halosulfuron (g ai/ha)	Diazinon (g ai/ha)					Means
	0	**140**	**280**	**420**	**560**	$\overline{X}$
	---------------------------	--------------------------- %	---------------------------	---------------------------	---------------------------	---- % ----
0	0	--	--	--	--	0 C
1.68	38	81	76	34	23	51 A
2.13	34	36	39	8	28	29 B
2.91	53	31	33	59	78	51 A
3.92	46	54	66	81	88	67 A
$\overline{X}$	34 A*	51 A	54 A	46 A	55 A	

*Main effects followed by the same letter are not different according to Waller Duncan Multiple Range Test ($P \leq 0.05$). $LSD_{0.05}$ between any two individual treatment means is 2.

CHAPTER 6

FINAL DISCUSSION

Yellow nutsedge is a major problem in croplands worldwide (Holm et al. 1977; Earl et al., 2004). It has the ability to puncture plastic mulch rendering it useless for multiple crop applications. Results from previous studies conducted by Christopher et al. (1994) and Minton et al. (2008) as well as the variously reported negative effects of sulfonylurea and organophosphate combinations led to the hypothesis that tank mixtures of selected sulfonylureas and diazinon can suppress a yellow nutsedge population.

Greenhouse experiments showed that combinations of halosulfuron and diazinon could decrease a nutsedge population by upwards of 90 to 100 percent. A synergism between halosulfuron and diazinon was observed. Also, the diazinon present in these combinations offers the potential for cutworm control. However, results from the field were not completely representative of those seen in the greenhouse. Penetration of the plastic mulch by yellow nutsedge rendered it useless for multiple crop applications.

Field trials revealed no synergism between the two pesticides. Such results may be due, in part, to irregular rain and an inconsistent nutsedge population, (1.7 plants/plot) in one location (E. V. Smith) and an overbearing nutsedge problem (450 plants/m^2) in the other location (Headland). Lack of control with these preemergence applications may also be due to a much faster degradation underneath plastic mulch. These studies were able to show that halosulfuron and diazinon combinations could effectively be applied via drip irrigation, saving a producer both time and money. Experiments observing halosulfuron and diazinon combinations were exhausted, but gave some promise to alternative combinations of sulfonylureas and organophosphates.

Trifloxysulfuron is not currently recommended for soil application due to its low level of soil activity. However, a synergism between trifloxysulfuron and diazinon was observed in the greenhouse, suggesting that follow-up field research should be conducted.

Greenhouse studies with combinations of halosulfuron and diazinon revealed promise for increased yellow nutsedge control. However, these results were not supported in the field. Methyl bromide was the unmistakable leader in vegetable crop weed control in the twentieth century, but as of 2005 its availability has been severely limited due to stratospheric ozone depletion (Johnson and Mullinix, 2006; U.S. Department of Agriculture USDA, 2009). However, an alternative to methyl bromide's efficacy, cost, ease of use, and availability has not surfaced yet (Sydorovych et al., 2008). Selected combinations of trifloxysulfuron and diazinon do hold some promise for yellow nutsedge control. There is need to evaluate these combinations in the field via preemergence injection and spraying.

LITERATURE CITED

Christopher, J. T., C. Preston, and S. Powles. 1994. Malathion antagonizes metabolism-based chlorsulfuron resistance in *Lolium rigidum*. Pesticide Biochem. and Physiol. 49:172-182.

Earl, H. J., J. A. Ferrell, W. K. Vencill, M. W. van Iersel, M. A. Czarnota. 2004. Effects of three herbicides on whole-plant carbon fixation and water use by yellow nutsedge (*Cyperus esculentus*). Weed Sci. 52:213-216.

Holm, L. G., D. C. Plunknett, J.V. Pancho, and J.P. Herberger. 1977. The World's Worst Weeds: Distribution and Biology. Honolulu, HI: Univ. Press of Hawaii. Pp. 125-133.

Johnson III, W. C. and B. G. Mullinix Jr. 2006. Yellow nutsedge (*Cyperus esculentus*) control with metam-sodium in transplanted cantaloupe (*Cucmis melo*). Crop Protection 26:867-871.

Minton, B., M. Matocha, and S. Senseman. 2008. The influence of malathion on trifloxysulfuron absorption and translocation in cotton. Cotton Sci. 12:48-52.

Sydorovych, O., C. D. Safley, R. M. Welker, L. M. Ferguson, D. W. Monks, K. Jennings, J. Driver, and F. J. Louws. 2008. Economic evaluation of methyl bromide alternatives for the production of tomatoes in North Carolina. Hort. Technol. 18(4):705-713.

U.S. Department of Agriculture. 2009. Methyl bromide. Agricultural Research Service. 10 Sept. 2009. http://www.ars.usda.gov/Research/docs.htm?docid=10408.