WEED SCIENCE EDUCATION AND RESEARCH: THE AGRONOMY LEARNING FARM AND MESOTRIONE AND SULFONYLUREA HERBICIDE INTERACTIONS

by

CHRISTOPHER LOUIS SCHUSTER

B.S., University of Missouri, 2001

M.S., University of Missouri, 2003

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agronomy

College of Agriculture

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Abstract

This dissertation has two complementary components: educational, in a survey of students in Weed Science and their perception of the Kansas state University Agronomy Learning farm, and research, regarding interactions between mesotrione and sulfonylurea herbicides. The Learning Farm serves as a resource where undergraduate students at KSU can develop agronomic skills through hands-on field site experiences and investigations. Students' perceptions of experiential learning activities in the development of problem-solving and critical thinking skills were studied as a result of the Learning Farm. Activities included: undergraduate students in Weed Science (AGRON 330) developing a weed management recommendation, and Undergraduate Research Assistants (URAs) conducting weed science research projects at the Learning Farm. Students stated that experiential learning activities increased their critical thinking skills, required effective time management, and presented concepts that could be used in other situations. Pre- and post-project evaluation questionnaires showed that URAs had an increased interest in agronomy, weed science, and research following the completion of their project. For the research project, field and greenhouse studies were conducted from 2003 to 2006 to evaluate the efficacy of various sulfonylurea herbicides when applied with mesotrione or mesotrione + atrazine. Research demonstrated that the addition of mesotrione to sulfonylurea herbicides decreased efficacy of sulfonylurea herbicides on green foxtail, yellow foxtail, and shattercane. The addition of atrazine to the tank mix, or increased mesotrione rates, resulted in additional decrease in sulfonylurea herbicide efficacy on shattercane and foxtail species. Additional studies were performed to determine if absorption, translocation, or metabolism was the basis for the reduction in sulfonylurea herbicide efficacy when mixed with mesotrione or

mesotrione + atrazine. Results indicated that the cause of antagonistic interaction between mesotrione and sulfonylurea herbicides in green and yellow foxtail was reduced absorption and translocation of the sulfonylurea herbicides. Producers who choose to apply mesotrione and sulfonylurea herbicides to corn should apply the herbicides sequentially to achieve maximum control of weedy grass species.

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This dissertation is dedicated to my wife Debbie and son Cole, I love you both very much. I much appreciated thank you must be given to my wife Debbie who has been with me every step of the way in attaining this degree, from my first visit to KSU to my Dissertation Defense. I also need to thank my father Jerry and brother Dan for the crop production advice and my mother Maryann and sister Cindy for all they have done for me and my family.

"To my brother Dan, cutting wheat in Kansas is fun, but not when you are cutting wheat with a Gleaner F2 that has no air conditioning in late June and the temperature is 101 °F."

CHAPTER 1 - Enhancement of Agronomy Education through Hands-on Learning Farm

ABSTRACT

The Agronomy Learning Farm is a resource available to undergraduate students at Kansas State University (KSU), to help develop agronomic skills through hands-on field site experiences and investigations. A qualitative approach was used to collect and analyze data regarding undergraduate student involvement, impressions, and the development of skills as a result of participation in the Learning Farm. Three groups of students were surveyed: students enrolled in Crop Science (AGRON 220) that conducted a hands-on learning activity at the Learning Farm, graduating seniors from the Department of Agronomy, and Undergraduate Research Assistants that conducted research at the Learning Farm. To maintain the validity of the study, multiple years of evidence were collected from all three groups of students. Student response to the Learning Farm was very favorable. Comments returned on questionnaires from the three groups of students indicated that students perceived practical value in the approach and focus of the Learning Farm. The Learning Farm provided students the opportunity to improve critical thinking, problem-solving, and time management skills; all of which employers perceive as important skills in new employees.

Key words: Agronomy research, experiential-learning, harvest loss, planter calibration.

INTRODUCTION

Modern agricultural systems have become more complex as agriculture advances in the areas of genetics, breeding, biotechnology, application technologies and equipment, and computer-based decision software (Battle and Arnholt 2003; Francis 2000; Gerhards and Oebel 2006; Wilkins 1996). Employers have indicated that students should gain diagnostic, practical, and technical training before embarking on full-time employment. Based on employer assessments of Agricultural students' skill preparation, it was noted that many graduates have not acquired the knowledge, competencies, skills, and abilities to accommodate employers' needs while in college (Andelt et al. 1997). The "ability to listen and carryout instructions" was ranked as the most important communication skill employers require in recent college graduates, with "ability to read and understand specific technical information" and "ability to contribute to group discussions and decisions" ranked next (Andelt et al. 1997). The most important leadership skills desired were "ability to work within a team to make decisions" and "demonstrate problem-solving ability" (Andelt et al. 1997). The lack of skills required to meet expectations of employers has created a need for change in the approach to education of undergraduate students in agriculture.

Higher education appears to be more resistant to innovation and change than the agricultural business or industry (Spence 2001). Teaching style in many of today's agricultural classes is composed primarily of lecturing without active engagement of students in learning activities (Claxton and Murrell 1987). Previous research, however, indicates that to be successful in preparing students for future employment, teachers should use a variety of teaching strategies dependent on their student audience (Joyce and Harootunian 1967). Research on the learning styles of students enrolled in agriculture generally portrays them as concrete learners (Cano and Garton 1994; Dyer and Osborne 1996). Concrete learners possess a style of learning which promotes the effectiveness of student-centered learning activities. As such, these students usually prefer more action-oriented teaching styles like experience-based learning activities (Cox et al. 1988). Experience-based learning activities include class periods devoted to discovery learning activities, hands-on learning laboratories, student-centered in-class and outdoor activities, and field trips (Bruening et al. 2002). These activities in the curriculum not only provide potentially engaging methods of learning, but they provide opportunities for putting that acquired knowledge into practice.

Experience-based learning, though, is more than simply having several student-centered activities in the lesson plan. Bruening et al. (2002) reported that the experiences must be meaningful, high-quality, and student-centered. If experience-based learning activities are negative or restrictive, they could reduce future positive learning experiences, or even decrease students' desire to learn (Howard and Yoder 1987). The educational value of an experience-based learning activity lies in what the learner takes away from it. Examining the learners' perceptions of an experience is a necessary component of determining the value and effectiveness of an experience-based activity (Bruening et al. 2002). The underlying belief is that if coursework and multifaceted teaching styles are properly designed to convey educational information, a high level of active learning should occur within students. This level, however, is not achieved directly through a teaching style and/or coursework, but is also dependent on the students' preferred learning style.

Learning styles of students are often studied at four levels: personality, information processing, social interaction, and instructional methods (Claxton and Murrell 1987). Witkin

(1976) identified learners by their ability to deal with “fields,” either independently or as a whole. The fields used were simple figures embedded in complex figures. By ascertaining an individual’s ability to locate a simple figure within an organized, complex figure, an individual could be classified as either having a field-dependent or -independent learning style. Field-independent learners were better able to discern individual components and learn well in an interactive setting, while field-dependent learners tended to be more social, have a more global perspective, and learn more effectively in a classroom environment. Witkin (1976) also noted in a review of literature that there seemed to be a relationship between careers selected by individuals and their learning style. He found that field-independent learners preferred careers that required the use of their analytical and problem-solving skills, such as engineering and biological sciences; whereas field-dependent learners preferred careers that required interpersonal skills such as social sciences, elementary school teaching, and management.

Agricultural students generally are portrayed as field-independent learners and as such these students usually enjoy more experience-based learning activities (Howard and Yoder 1987; Rudd et al. 1998). Research has shown that agriculture students usually retain the most practical information from hands-on learning laboratories, outdoor activities, and field trips are those where (Rollins 1990). These activities provided students with practical knowledge and allowed better interaction between teacher and student or student and student than traditional classroom lecturing (Bruening et al. 2002).

The Department of Agronomy at Kansas State University (KSU) should provide students with a learning experience that promotes development of the necessary technical skills and intellectual competencies they need for successful employment. Recent graduates from the Department have indicated through exit interviews, course evaluations, and during internship experience interviews, that they desire training, knowledge, and more experience-based learning opportunities. Currently, the Learning Farm is being developed to provide Agronomy students with hands-on field site experiences and investigations. The objective was to assess the benefits that the Learning Farm was providing to undergraduate students in Agronomy at KSU.

AGRONOMY LEARNING FARM

The KSU Department of Agronomy has ownership of the Agronomy North Farm, a 162-hectare facility located 4.8 km northwest of the Agronomy departmental building, Thockmorton Plant Sciences Center. The North Farm is used for limited field experimentation, foundation seed production, and extension/demonstration plots. It is a tremendous facility that many teaching and extension faculty already use, but in an *ad hoc* manner. Student involvement with the North Farm has been limited; however, through the establishment of a Learning Farm within the North Farm, a new resource has been provided to undergraduate students wanting to receive hands-on learning experiences.

The Learning Farm is supported by a USDA-CSREES Higher Education Challenge grant and a cooperative effort among College of Agriculture and Department of Agronomy teaching faculty. The Learning Farm encompasses 32 hectares, which is divided into a long-range plan of crop and tillage rotations. This area was divided into three zones. The soil building zone consists of four hectares in three different alfalfa varieties. The second zone is an established no-tillage 3-year crop rotation system of grain sorghum – soybean – winter wheat on approximately 24 hectares. Each crop is produced following recommendations for crop production in Northeast Kansas. Depending on needs of instructors who anticipate using the Learning Farm, unique demonstrations can be incorporated into this zone so they are available for a particular course or laboratory exercise. The final zone composed of five separate fields is reserved for undergraduate students to conduct their own research studies.

Undergraduate students interact with the Learning Farm through class field trips, in-class research activities, and as undergraduate research assistants (URAs) supervised by departmental personnel. URAs are awarded an assistantship ($500/semester), select a research project, and with the supervision of a professor, perform the study, and have an opportunity to present findings of the research in a formal presentation (paper or poster). A list of previous URAs and their research projects are listed in Table 1.1.

Educational Benefits of the Agronomy Learning Farm

The research methodology used to collect and analyze data regarding educational benefits of the Learning Farm in reference to undergraduate involvement, impressions, and skill development was qualitative. Three groups of students were assessed in a qualitative approach: students enrolled in Crop Science (AGRON 220) that conducted a hands-on learning activity at the Learning Farm, graduating seniors from the Department of Agronomy, and Learning Farm URAs. To maintain validity of the study, multiple years of evidence were collected from all three groups of students who participated in activities at the Learning Farm.

Group #1: Crop Science Students' Evaluation of Hands-on Learning Activity

Enrollment in Crop Science is comprised of students interested in underlying practices used in the culture of corn, grain sorghum, wheat, and soybeans. It is a basic course for majors in Agronomy and others interested in crop production within the College of Agriculture. The course consists of three hours of lecture and a two-hour laboratory each week. The focus of the laboratory is crop growth stage identification, aspects of crop production (e.g. soil preparation, planting, harvesting), and providing students with hands-on learning activities which cannot be included in a traditional classroom lecture.

The activity at the Learning Farm was "Calibration and Yield Losses" consisting of three exercises: 1. field calibration of a planter, 2. field calibration of a grain drill, and 3. an in-field determination of yield loss from a combine during harvest. Attendance by laboratory sections ranged from 7 to 22 students divided into three groups, and students were led through each exercise by a Laboratory Teaching Assistant, Learning Farm Coordinator, or a URA. Calibration problems and yield loss scenarios were designed to challenge students with real-world issues they might encounter while on the job or on their own farms.

Prior to the actual field trip to the Learning Farm, students had attended two weeks of laboratory sessions on field crop planting, agronomic calculations (e.g. seedling rate, germination, emergence) and the basis of determining harvest loss of corn, grain sorghum, soybean, and wheat. The field trip took place during the first week of April in 2006 and third week of October in 2005 and 2006, with a written assignment due the following week in the laboratory (Figure 1.1). The first station was comprised of a John Deere 7200 MaxEmerge® 2 Drawn Standard Planter[1] with the objective to calibrate the planter and each of the six rows to accurately plant corn at a given seed/plant population. The second station was calibration of a John Deere 750 Grain Drill[2] to accurately sow winter wheat or soybean depending on the semester (winter wheat in fall and soybean in spring), at a given seed/plant population. The third station was to determine harvest loss. In the Fall semesters of 2005 and 2006, a Gleaner F2 Self Propelled Combine[3] had harvested a 50 m strip of grain sorghum and students were asked to examine the field and determine grain loss. In the Spring semester of 2006, when crops were unavailable for harvest, wheat seeds were spread in wheat stubble with a hand-seeder and students were asked to determine grain loss.

Student assessments of this experience-based learning activity and calibration equations were done immediately after students submitted their written laboratory assignment. Twelve statements were rated on a scale of 1 to 5, with 1 being strong agreement, 3 as neutral, and 5 as strong disagreement (Table 1.2). Three sets (Fall 2005 & 2006, Spring 2006) of data were collected from students for a total of 107 responses. The correlation procedure in SAS (2002) was used to determine associations between student perceptions of the learning activity as a valuable activity and other responses (Table 1.3). A questionnaire was also completed by instructors of Crop Science (n = 6) to determine their assessment of the learning activity.

Group #2: Educational Benefits for Graduating Seniors in Agronomy

The Department of Agronomy had 24 and 19 students graduate in 2005 and 2006, respectively (Dana Minihan, Assistant Academic Coordinator, personal communication). These students had pursued studies in plants, soils, and environmental sciences by selecting one of the following five options: Business & Industry, Consulting & Production, Plant Science & Biotechnology, Soil & Environmental Science, or Range Management. The Department of Agronomy had 100% placement of graduates who are employed as county agents, crop consultants for independent businesses, cooperatives, fertilizer, chemical or crop seed dealers, and by federal or state agencies such as Natural Resource Conservation Service (NRCS) and the State of Kansas Department of Agriculture, return to production agriculture, or begin graduate school.

Prior to graduation, seniors have been asked to complete an exit survey regarding their educational experience in the Department of Agronomy. An additional questionnaire pertaining to the Learning Farm was included in the 2005 and 2006 surveys (Figure 1.2). The questionnaire contained open-ended questions to determine previous experiences with the Learning Farm, classes in which they were enrolled that visited the Learning Farm, and the type(s) of activities they conducted while visiting the Learning Farm. The purpose of the Learning Farm questionnaire was to explore the students' perceptions of the benefit of the Learning Farm related to their educational experience at KSU. These questions also evaluated the students' perceptions of whether the Learning Farm was providing the correct foundation to help build their problem-solving and critical thinking skills, and their ability to work in a team.

Group #3: Educational Benefits for Undergraduate Research Assistants

Learning Farm URAs assisted with day-to-day field operations and selected a research study under a professor or graduate student mentor in the Department of Agronomy. The population of this study consisted of all URAs (n = 8) completing a research study on the Learning Farm from September 2003 to December 2006. An ideal sample would have included a diversity of undergraduate students from various agricultural backgrounds, genders, races, and countries of origin. Practicality, however, required adjustments to the selection of group #3 members were based on research interests and the availability of research studies. Specific studies were selected because they were either of interest to the student or professor, currently had funding, or had potential of being funded, and could be completed within a two-semester time frame.

Questionnaires were presented to students following completion of the project (Table 1.4). Students were asked to rate the experience on a scale of 1 to 5, as previously described. Additionally, for those URAs who graduated from KSU, a post-graduation survey was given to them to answer how this experience helped them in their future endeavors (n = 4). Post-project and post-graduation questionnaires explored the students' perceptions about the development and procedure of completing a research project and their perceptions regarding the educational value of the Learning Farm. These questions also attempted to discern knowledge gained from completing a research project and self-revelation of students' attitudes toward the field of agronomy. A student's major and Agronomy option was noted on the questionnaire. Correlations between student's response of the value of the Learning Farm following completion of the study and response of other post-project evaluation questions were done using the correlation procedure in SAS (SAS 2002).

RESULTS AND DISCUSSION

Surveys indicated that since February 2004, the Learning Farm had been visited by 934 undergraduate students attending KSU. The majority of these students were enrolled in one of four classes that conduct hands-on learning laboratories every semester they are offered at the Learning Farm. Additional students that visited the Learning Farm either were URAs, student hourly workers, or were a member of the KSU Collegiate Crop, Soil, or Weed Team. Students completed questionnaires following their visit(s) to the Learning Farm and from those questionnaires it was noted that greater than 98% of students visiting the Learning Farm were in the College of Agriculture and 45% were obtaining a Bachelor of Science degree in Agronomy. The majority of students majoring in Agronomy were expected to visit the Learning Farm at least four times prior to graduation.

Group #1

The instructor or Learning Farm Coordinator led a brief discussion on the particular piece of equipment at the station, which included make and model, general uses (e.g. planting corn, grain sorghum, and soybean), maintenance, and price. Interestingly, most students were surprised by the price of the farm equipment and had never considered the actual investment it takes to successfully produce a crop. Students were then given an assignment and with the assistance of the instructor or Learning Farm coordinator, instructed on how to complete the assignment successfully. Instructor participation in the station varied among groups and between laboratory sections, as groups had a range of previous experience and skills in planter and grain drill calibration and yield loss determination.

The majority of students were positive in rating the “value of the activity”, with a rating of 1.3 (Table 1.2). They gave a similar rating to the learning activity’s “ability to provide the student with knowledge to accurately calibrate a planter/grain drill” and “providing an increased understanding of crop planting equipment.” The strengths of the activity were its ability to provide concepts that could be transferred to other situations and improving the student’s ability to receive information through observation. Students also indicated that peer interaction in this learning activity was beneficial, a trait often cited by employers as being critically important but generally lacking in recent college graduates (Andelt et al. 1997). Interestingly, students were neutral as to whether the activity provided insight into a production practice they had never before considered and provided an increased understanding of seed placement in the soil upon the completion of this exercise. A possible explanation for the low rating of an increased understanding of seed placement in the soil was that 5 out of the 9 times when the laboratory was conducted, it was either raining or had previously rained, and the planter and grain drill calibration had to be completed inside a machine shed at the Learning Farm.

There was a relationship between the students viewing this activity as valuable compared to the other assessment questions with four significant correlations (Table 1.3). Students’ who viewed the activity as valuable also thought they had an increased understanding of crop planting equipment, general farming practices, and received the knowledge and training required to accurately calibrate a planter and grain drill after completing the activity. Also, students who viewed the experience-based learning activity as valuable agreed that they would be interested in more hands-on learning in their educational program.

Six different Crop Science instructors assisted in this experience-based learning activity. All instructors agreed this hands-on learning activity was quite successful at demonstrating practices and procedures required to calibrate a planter and grain drill and to determine yield loss following harvest. The timing and duration of the experiential learning activity, however, could be more beneficial to students if it was performed during two separate laboratory sessions, as instructors agreed that both students and instructors had to be very time efficient to complete the learning activity (Table 1.2). It was difficult complete in a single 2-hour laboratory session, including transportation between the departmental building and the Learning Farm. Students struggled at times with the complexity of calculations and the challenge of recording the required information in an outdoor setting, where there was extensive background noise and activity. Instructors, however, did respond that students would have learned the information less effectively if presented in the classroom as compared to the activity being performed at the Learning Farm, with a ranking of 1.8 (Table 1.2).

One suggested improvement to this activity included having all students perform some role at each station. While allowing every student to calibrate the planter and grain drill individually would be practically impossible, ensuring that each student had an assignment in the calibration procedure would potentially build self-confidence, increase participation, and ensure students remained focused on the problem-solving task at hand. Instructor perceptions were that the students actually performing the calibration tasks were those who had a more in-depth understanding of the process.

Group #2

In 2005 and 2006, 46 and 84% of the graduating seniors completed and returned the questionnaire regarding the Learning Farm, respectively. Of the 27 students that completed the survey, only one indicated no involvement with the Learning Farm. This student did, however, responded with "I feel a good education in agriculture should be about 80% hands-on." The remaining 26 graduating seniors that had an interaction with the Learning Farm, either served as Summer Interns or URAs with the Learning Farm, used the Learning Farm for a contest practice area, or were enrolled in classes that visited the Learning Farm. Questionnaires indicated that 95% of those students were enrolled in multiple courses that conducted an experimental learning activity at the Learning Farm. These students were enrolled in Crop Science, Weed Science (AGRON 330), Soil Fertility Laboratory (AGRON 385), and Crop Diseases (PLPTH 585), with Crop Science, Soil Fertility, and Weed Science making multiple trips to the Learning Farm during the semesters they were offered.

Responses regarding the Learning Farm were quite positive and students provided excellent feedback on many of the questions regarding use of the farm and benefits they received from its use in classes. In the questionnaire, graduating seniors were asked to rate their learning experience at the Learning Farm from 1 to 5, as previously described. The overall average of the 26 students which rated their learning experience at the Learning Farm was 1.8 (data not shown). Comments from students about their learning experience at the Learning Farm included "Hands-on experiences help students apply the knowledge learned in the classroom to real-world agronomic problems", "It is difficult to learn to calibrate a sprayer or evaluate a soil pit without actually doing it, and you can't bring a sprayer or soil pit into the classroom", and "There is very little done in the field of agronomy that wouldn't be considered hands-on, why should our classes be any different."

Graduating seniors were also asked how the Learning Farm was beneficial to their educational program and what improvements were needed. The overall response by students was that the Learning Farm provided students a chance to see first hand various farming practices and machinery, and this experience helped students understand the underlying principles of complex agriculture systems of today. Students also appreciated the closeness of the Learning Farm in proximity to the Departmental building, which made for easy access to the Learning Farm. Suggested improvements for the Learning Farm were that it should be used more often and in more of the classes offered in the Agronomy curriculum.

Group #3

URAs had the most opportunities to participate on the Learning Farm, as they were enrolled in classes that visited the Learning Farm, assisted with day-to-day operations on the farm, and conducted their own research project at the Learning Farm. Since the initiation of the Learning Farm in 2002, ten undergraduates, at KSU had an opportunity to conduct a research project. It was not until the Fall of 2003 that students began completing questionnaires regarding the benefits of the Learning Farm. As a result, eight students received the post-project and/or post-graduation questionnaires regarding the benefits of the Learning Farm for undergraduate research. Interestingly, only five of the eight students were majoring in Agronomy, while the others majored in Agricultural Business or Agricultural Engineering. There were, however, no differences in students' responses to the questions based on major or Agronomy option (data not shown).

Post-project evaluation indicated that undergraduate research conducted at the Learning Farm was a valuable activity, with a rating of 1.2 (Table 1.4). A similar rating was obtained for the improvement of critical thinking, problem-solving, and time management skills. Students, however, were more neutral to improvement in the ability to analyze research data and ability to present research data. This could possibly be related to the short 1- or 2-semster time frame to complete the research; may not have been the led investigator on project but assisting the faculty or graduate student mentor; were not receiving any formal grade as a result of participating in a URA – thus not the same expectations; and no commitment for full completion of project toward data analyses and summarization and eventual poster or paper presentation.

Since the initiation of the Learning Farm, four of the eight students completing the post-project evaluation have graduated. The post-graduation evaluations indicated URAs have a heightened interest in agronomy and that they were able to transfer concepts learned at the Learning Farm to their current position. The post-graduation evaluation of the value of their research experience at the Learning Farm was identical to their post-project evaluation, with a rating of 1.2 (Table 1.4).

Correlation analysis indicated that students who viewed the research experience as valuable thought it improved their abilities in three of the six skill categories associated with the experiential-based learning activity (Table 1.5). However, significant correlations were not detected between perception of completing a research project as valuable and increased ability to collect information effectively through observation and improved ability to present research data. The lack of correlation for these two outcomes most likely resulted from students needing more practice in collecting observational data and the presenting of research data not being a requirement for URAs. Correlations were significant between the assessment of the value of completing a research project and the comment that the Learning Farm was beneficial in the student's agronomy education. Additionally, all students surveyed indicated that they would recommend students majoring in Agronomy to conduct a research project before graduation.

CONCLUSIONS

Dewey (1938) and many others have indicated that the quality of a learning experience is important to students' success after graduation. This includes the students' perceptions of the quality of the learning experience, not solely the educator's intent behind the activity. Properly facilitated learning through meaningful experiences is known to have direct and lasting benefits to the learner (Conrad and Hedin 1995; Jernstedt 1980). Students' responses to hands-on activities at the Learning Farm were very favorable, and they perceived that there was practical value in the learning approach and focus of the Learning Farm. Students appreciated the value of problem-based learning and felt that it enhanced their ability to objectively and constructively appraise problematic situations. Higher education that merely seeks to train employees for agricultural careers need to re-think their objective and instead strive to prepare students to be critical and constructive members of their society.

SOURCES OF MATERIALS

[1] 7200 MaxEmerge® 2 Drawn Standard Planters, John Deere Company, 3210 East 85th Street, Southeast Station, Kansas City, MO 64132-2586.

[2] 750 Grain Drills, John Deere Company, 3210 East 85th Street, Southeast Station, Kansas City, MO 64132-2586.

[3] Gleaner F2 Self-Propelled Combine, Allis-Chalmers, Agricultural Equipment Division, Box 512, Milwaukee, WI, 53201.

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Table 1.1 Undergraduate student research assistants at the Agronomy Learning Farm, dates in program, project title, and their current position between Fall 2002 and present.

Name	Dates	Project Title	Current Position
Lance Kendig	Fall 2002- Spring 2003	Soil pH Titration Curves	Kansas Crop Consultant
Justin Gatz	Fall 2002- Spring 2003	Weed Mapping on Agronomy Learning Farm	Kansas Crop Consultant
Jon-Joseph Armstrong	Fall 2003- Spring 2004	Correlation of Site-specific Properties and Emergence of Winter Annual Weeds	MSU Ph.D. degree
Joseph Blecha	Fall 2003- Spring 2004	Velvetleaf Emergence from Different Depths in Greenhouse and Field	KCKCC Pharmacy
Matthew Meyerhoff	Summer 2004	Soil Humus Development within Different Residues in the Field	NRCS Employee
William Hall	Summer 2004	Internship – AGRON 405 Feed Value Analysis of Alfalfa	KSU M.S. Degree
Michael Duff	Fall 2004- Spring 2005	Glyphosate Dose-response of Hophornbeam Copperleaf (*Acalypha ostryifolia*)	KSU M.S. Degree
Kevin Bergman	Fall 2005- Spring 2006	Soil Profile Characteristics Across Fields at Learning Farm	Agriliance Employee
Scott Feldt	Summer 2006- Present	Response of Teff (*Eragrostis Tef*) to Various Herbicides in Eastern Kansas	KSU Learning Farm - URA
J. D. Riffel	Fall 2006- Present	Competitiveness of Teff (*Eragrostis Tef*) in Corn and Grain Sorghum	KSU Learning Farm - URA

Table 1.2. Student assessment and instructor perceptions of planter and grain drill calibration and harvest loss learning activity.[a]

Statement	Mean	Standard deviation
Student Assessment[b]		
This was a valuable activity.	1.3	0.56
The training I received provided knowledge to accurately calibrate a planter/grain drill.	1.4	0.69
I have an increased understanding of seed placement in the soil after completing this activity.	3.4	1.08
I have an increased understanding of crop planting equipment after completing this activity.	1.4	0.67
I have an increased understanding of general farm practices after completing this activity.	2.4	1.02
I can transfer the concepts learned in this activity to other situations.	1.9	0.96
This activity improved my ability to receive information effectively through observation.	1.9	0.68
This activity provided insight into production agriculture I never before considered.	2.8	1.11
This activity improved my critical thinking skills.	2.1	0.90
I would be interested in more hands-on learning activities.	1.2	0.36
Peer interaction in this learning activity was beneficial.	1.8	1.01
The calculation problems provided a good example of what we were doing in previous labs.	1.7	0.93
Instructor Perceptions[c]		
This was a valuable activity	1.2	0.41
Students response to hands-on learning was favorable	1.7	0.55
Students would have learned the information less effectively in a classroom setting.	1.8	0.75
Problem solving, critical thinking, and team work were incorporated into the learning activity.	1.2	0.41
Students and instructors had to be time efficient to complete the learning activity.	1.0	0.00
Students' listened and carried out instructions as directed.	1.5	0.55
Students calibration of planter/grain drill was successful enough for use of machine on Farm	1.8	0.41

[a]Responses to each statement were rated on a scale of 1 to 5. 1 = strongly agree, 3 = neutral, and 5 = strongly disagree.
[b]Sample size = 107.
[c]Sample size = 6.

Table 1.3. Correlations between student assessment of the planter and grain drill calibration and harvest loss learning activity as a valuable experience (the first statement in Table 1.2) and other evaluating statements.

Statement	Coefficient of correlation (*r*)	P > r
The training I received provided knowledge to accurately calibrate a planter/grain drill.	0.74	<0.001
I have an increased understanding of seed placement in the soil after completing this activity.	0.02	0.648
I have an increased understanding of crop planting equipment after completing this activity.	0.74	<0.001
I have an increased understanding of general farm practices after completing this activity.	0.50	0.046
I can transfer the concepts learned in this activity to other situations.	0.34	0.164
This activity improved my ability to receive information effectively through observation.	0.41	0.082
This activity provided insight into production agriculture I never before considered.	0.04	0.522
This activity improved my critical thinking skills.	0.03	0.581
I would be interested in more hands-on learning activities.	0.51	0.042
Peer interaction in this learning activity was beneficial.	0.14	0.263
The calculation problems provided a good example of what we were doing in previous labs.	0.32	0.192

Table 1.4. Post-project and post-graduation evaluation of undergraduate research assistantships at the Agronomy Learning Farm.[a]

Statement	Mean	Standard deviation
Post-Project Evaluation[b]		
This was a valuable activity.	1.2	0.45
This activity improved my ability to receive information effectively through observation.	1.8	0.84
This activity improved my ability to analyze research data.	2.8	0.84
This activity improved my critical thinking skills.	1.4	0.55
This activity improved my problem-solving skills.	1.4	0.45
This activity improved my time management skills.	1.4	0.45
This activity improved my ability to present research data.	2.8	1.00
I can transfer the concepts learned in this activity to other situations.	1.6	0.55
The Learning Farm provided a chance to conduct research otherwise unavailable.	1.8	0.45
The Learning Farm was beneficial in my Agronomy education.	1.4	0.55
I would recommend for all students in Agronomy to conduct research.	1.2	0.45
Post-Graduation Evaluation[c]		
This was a valuable activity.	1.2	0.45
This activity increased my interest in agronomy.	1.4	0.55
This activity increased my understanding of research procedures.	1.6	0.55
Concepts I learned at the Learning Farm were transferred to my current position.	1.2	0.45

[a]Responses to each statement were rated on a scale of 1 to 5. 1 = strongly agree, 3 = neutral, and 5 = strongly disagree.
[b]Sample size = 8.
[c]Sample size = 4.

Table 1.5. Correlations between student assessment of the value of completing a research project (the first statement under post-project evaluation in Table 1.4) and other evaluating statements.

Statement	Coefficient of correlation (*r*)	P > r
This activity improved my ability to receive information effectively through observation.	0.08	0.521
This activity improved my ability to analyze research data.	0.22	0.272
This activity improved my critical thinking skills.	0.65	0.041
This activity improved my problem-solving skills.	0.71	<0.001
This activity improved my time management skills.	0.65	0.041
This activity improved my ability to present research data.	0.44	0.091
I can transfer the concepts learned in this activity to other situations.	0.29	0.322
The Learning Farm provided a chance to conduct research otherwise unavailable.	0.14	0.381
The Learning Farm was beneficial in my Agronomy education.	0.65	0.015
I would recommend for all students in Agronomy to conduct research.	1.00	<0.001

AGRONOMY 220 LAB Name________________________
Grain Drill and Planter Calibration
Estimating Harvest Loss Lab time ______________________

Grain Drill Calibration

Drive Wheel Circumference__________inches _________feet

Drill Row Spacing___________inches

Number of Revolutions________________

Calibration Run Travel Distance__________________feet

Collected Grain Weight:

Hole #1_________	Hole #2__________	Hole #3__________
Hole# 4__________	Hole #5__________	Hole #6__________

Average grain weight collected per hole_____________grams

Calculated Seeding Rate (Pounds/A)______________________

Planter Calibration

Planter Row Spacing_____________inches ____________feet

Number of row feet/A=________________

1/1000 of acre row feet= _______________

Number of seeds counted in 1/1000 row feet

Row#1_________	Row#2_________	Row#3_________
Row#4_________	Row#5_________	Row#6_________
Average count__________	Plant population_______________	

Corn Harvest Loss

Shelled Corn = 56 lbs / bushel

Size of area for estimation of loss________ft^2

Number of seeds in estimation areas

Area#1________	Area#2________	Area#3________
Area#4________	Area#5________	Area#6________

Average seed count_________

Number of seeds per acre_____________

Number of pounds of seed per acre (~1350 seeds/pound)_____________

Estimated Number of Bushels per acre lost at Harvest_____________

Figure 1.1. Grain drill and planter calibration and estimating harvest loss worksheet for Crop Science (AGRON 220) Laboratory.

Are you familiar with the Agronomy Learning Farm? _____Yes (go to *A*) ______No (go to *B*)

A. If yes, what experience have you had with the Learning Farm? *mark all that apply*

_______Summer Internship

_______Undergraduate Research Assistant (Fall or Spring Semester)

_______Practice Area for Contest

_______Class Field Trip/Learning Exercise

_______Other (explain)

Mark All Classes in which you visited the Learning Farm

__Crop Science (AGRON 220) __Soils (AGRON 305)

__Weed Management (AGRON 330) __Soil Fertility (AGRON 375) and Lab (385)

__Soil Genesis and Classification (AGRON 515)

__Crop Diseases (PLPTH 585) __Site Specific Agriculture (AGRON 655)

__Agricultural Machinery Systems and Laboratory (ATM 330 and ATM 335)

What types of activity(s) did you do during your visit?

How would you rate your learning experience with the Learning Farm? *circle one*

1. Excellent 2. Good 3. Average 4. Fair 5. Poor

The goal of the Agronomy Learning Farm is to give students "Hands-on Experiences" they might not experience in the classroom or laboratory. Do you agree or disagree with this statement? Why?

From your experience with the Learning Farm, what was BENEFICIAL about the facility and what NEEDS IMPROVEMENT?

B. If no, after reading the above description what is your initial impression about the Learning Farm?

The goal of the Agronomy Learning Farm is to give students "Hands-on Experiences" they might not experience in the classroom. Would you have liked more hands-on experiences during your educational program at KSU?

Figure 1.2. Questionnaire regarding use and implications of the Agronomy Learning Farm presented to graduating seniors in the Department of Agronomy.

CHAPTER 2 - Weed Science Projects Designed to Enhance Problem-solving and Critical Thinking Skills in Undergraduate Students

ABSTRACT

Undergraduate education must provide students with specific skills for successful employment. Students need to be technically competent but must also develop skills in team work, problem-solving, and critical thinking. Weed science projects were conducted at the Kansas State University Agronomy Learning Farm to examine students' perceptions of experiential learning activities in the development of their problem-solving and critical thinking skills. The first activity consisted of students in the undergraduate Weed Science (AGRON 330) class developing a weed management recommendation; where they scouted three fields, used WeedSOFT® and additional resources, and then recommended a weed management practice to the producer of the fields. Questionnaires were used to determine the value of the activity. Students stated that the experiential learning activity increased their critical thinking skills, required effective time management, and presented concepts that could be used in other situations. Interestingly, students were neutral as to whether peer interaction in this exercise actually proved beneficial to the learning process, which was one of the objectives of this learning experience. An additional activity evaluated the benefits of undergraduate research with respect to student skill development. Multiple students served as Undergraduate Research Assistants (URAs) at the Agronomy Learning Farm and each student conducted a weed science research project with the assistance of a mentor. Pre- and post-project questionnaires showed that URAs interests in agronomy, weed science, and research were increased following the completion of their project. Statements about the experiences indicated that the activities were valuable to their educational experience and that they desired more hands-on learning activities.

Key words: Crop scouting, education, hands-on learning, WeedSOFT®.

Abbreviations: URAs, Undergraduate Research Assistants.

INTRODUCTION

Experiential learning is an integrative approach to learning that combines experience, perception, cognition, and behavior, that provides a link between the classroom and the real world (Kolb 1984). Programs that emphasize experiential learning typically include both in-classroom components and real world components, which are jointly and cooperatively supervised by school and work-site personnel (Pataniczek and Johansen 1983). Students exposed to experiential learning are simply more likely to internalize, understand, and remember material learned due to active engagement in the learning process (Bonwell and Sutherland 1996). Experiential learning is not a new innovation in education; however, emphasis on this type of learning has recently been recognized as an important teaching and learning concept for undergraduate education in agriculture. Salvador et al. (1995) indicated that students in an agriculture curriculum appreciated the practical nature of this teaching approach and felt that it enhanced their ability to appraise problematic situations constructively and objectively.

Experiential learning has had tremendous growth in recent years as educators have realized the benefit of using and accommodating a wider range of teaching and learning styles (Dyer and Osborne 1996). Teaching styles in agriculture range from lecturing or no active engagement of students in learning activities to completely student-centered learning activities (Claxton and Murrell 1987). To be successful, teachers should use a wide range of teaching styles dependent on their student audience (Joyce and Harootunian 1967). Research on the learning styles of students enrolled in agricultural programs portrays the majority as concrete learners (Cano and Garton 1994; Dyer and Osborne 1996). Concrete learners possess a style of learning which promotes the use of student-centered learning activities as very successful. As such, these students usually prefer more action-oriented experiential learning activities such as discovery learning activities, hands-on laboratories, student-centered in-class and outdoor activities, and field trips (Bruening et al. 2002, Cox et al. 1998). These activities woven throughout the curriculum not only provide potentially engaging methods of learning but they provide opportunities for the students to develop and practice problem-solving and critical thinking skills.

Problem-solving and critical thinking skills are among the most cited needs to support curriculum changes in Colleges of Agriculture (Downs and Mehlhorn 2003; Merritt and Hamm 1994; Rudd et al. 2000; Woods 1993). Problem-solving is at the very heart of agriculture since the very business of agriculturists is to solve problems, such as selecting the optimum time to plant a crop, determining the optimum fertilizer recommendation, or choosing an herbicide that will selectively control a weed within a crop. Critical thinking is defined as a higher-order of thinking activity that is self-directed, self-disciplined, self-monitored, and self-corrective (Burden and Byrd 1994). Critical thinking is an active and skillful analysis, application, and/or evaluation of information gathered from reflection, reasoning, communication, observation, and/or experience. Problem-solving and critical thinking skills in Colleges of Agriculture, and specifically in the field of Weed Science, have not been widely studied. Gibson and Liebman (2003a; 2003b), however, have indicated a significant positive correlation between students that think experiential learning activities in a Weed Science class are valuable and the ability of the activities to improve their critical thinking skills.

The purpose of this study was to examine the benefits and impact of experiential learning activities from the students' point of view. The objectives were to evaluate enhancement of problem-solving and critical thinking skills of undergraduates through two activities: 1) using a hands-on approach to develop a weed management recommendation, and 2) participating in undergraduate research projects.

AGRONOMY LEARNING FARM

The Department of Agronomy at Kansas State University (KSU) had 96, 100, and 100 undergraduate students enrolled at the end of the Fall 2004, 2005, and 2006 semesters, respectively (Dana Minihan, Assistant Academic Coordinator, personal communication). KSU Agronomy students pursue studies in plants, soils, and the environmental sciences by selecting one of the following five options: Business & Industry, Consulting & Production, Plant Science & Biotechnology, Soil & Environmental Science, or Range Management. Students from the Department of Agronomy have indicated through exit interviews, course evaluations, and during internship experience interviews that they desire more hands-on learning opportunities. Currently, the Agronomy Learning Farm is being developed to provide students with this type of learning experience.

The Learning Farm is supported by a USDA-CSREES Higher Education Challenge grant and a cooperative effort among College of Agriculture teaching faculty to incorporate a series of hands-on experiential learning activities for students throughout their four-year curriculum. Students in courses such as Crop Science (AGRON 220), Soils (AGRON 305), Soil Fertility (AGRON 375) and laboratory (AGRON 385), Crop Diseases (PLPTH 585), Agricultural Machinery Systems (BAE 350), Site Specific Agriculture (AGRON 655), and Weed Science (AGRON 330) have traveled to the Learning Farm for different laboratory experiences, data collection, analyses, pest identification, and developing recommendations. Student evaluations of these laboratories were taken to determine if the exercises were beneficial and if they increased students desire to learn more about a subject (Activity #1).

The Learning Farm is approximately 32 hectares at the Agronomy North Farm. These 32 hectares are divided into three zones. The soil building zone consists of four hectares in three different alfalfa varieties. The second zone is an established no-tillage 3-year crop rotation system of grain sorghum – soybean – winter wheat on approximately 24 hectares. Each crop is produced following recommendations for crop production in Northeast Kansas. The final zone is reserved for undergraduate students to conduct their own research experiments. During the academic year, students have been awarded undergraduate research assistantships ($500/semester) and participate in independent research projects together with a faculty or graduate student mentor. Undergraduate Research Assistants (URAs) select a research project, then with the supervision of a mentor, perform the experiment, and have the opportunity to present the findings of the research in a formal oral or poster presentation (Activity #2).

Activity #1: Developing a Weed Management Recommendation.

Weed Science is a required course for those students in Agronomy with the Business & Industry, Consulting & Production, or Plant Science & Biotechnology option. The course is designed for those interested in crop production, crop protection, and agricultural education. It considers the origin of weeds, their relations to crops, and control systems emphasizing cultural practices and herbicides. The course consists of two hours of lecture and a two-hour laboratory each week. The focus of the laboratory is weed identification, aspects of chemical weed control (e.g. application, calculations, calibration), and providing students with hands-on learning activities which cannot be included in the traditional classroom lecture.

One of the laboratory projects students in Weed Science are expected to complete is the development of weed management recommendations for three selected fields at the Learning Farm. For this project, groups of two to three students scouted selected fields and then prepared a weed management recommendation for the current condition of the field and for the upcoming growing season. Problems were designed to challenge students with real-world issues they might encounter while on the job or on their own farms.

Prior to the actual field exercise, students attended six laboratory sessions on weed identification, reviewed herbicidal control of weeds, and completed assignments on herbicide dosage calculations. Two earlier field trips to the Learning Farm included a visit to the weed nursery to observe mature plant species and another visit to discuss the correct method of field scouting. A representative form for pest scouting was made available to students prior to field scouting (Figure 2.1). Students also had a quick review of two decision-making resources: WeedSOFT®[1] and the Kansas Chemical Weed Control Guide[2], which were available for students to develop and prepare their weed management recommendations.

This laboratory activity took place during the first week of November in 2004, 2005, and 2006. Fields were selected by teaching assistants and the Learning Farm coordinator one week prior to the laboratory. Selected fields contained two to three dominant weed species and up to seven additional weed species. For those instances in which weather did not permit scouting of the fields during the designated laboratory period, a brief description of the field conditions were prepared that described the weed species present in the field and the density at which they were present. For example:

> "This is a highly productive 10-acre field that the producer would like to plant either corn or grain sorghum in the spring. Last year the field was in soybean that yielded 55.8 bushel per acre and the only herbicide used was glyphosate (two postemergence applications). The producer does not wish to use the same mode of action of herbicide

for two consecutive years. Common waterhemp (20 plants/m^2) and green foxtail (13 plants/m^2) are very problematic within the field during the summer.

The producer believes some winter annuals are currently growing in the field and, if there is, he wants to kill them this fall so they do not interfere with the planter in the spring. Scout the field and make a weed management recommendation for now and for next spring."

Students were, however, still required to scout the field. The students scouted the fields and were required to make observations at three key sampling areas marked with orange flags. These three areas were surveyed for weed species and densities by the laboratory teaching assistants prior to the completion of the project, as a comparison to reports on students' scouting forms. Written report summarizing the weed management recommendations for each field was turned in by the following laboratory session. Each group had to include the following in their recommendation: application rates (both active ingredient and formulation product per hectare), timing of application (PPI, PRE, POST), additives needed and rates, restrictions in use of the product (crop rotation, soil texture, counties, etc.), and cost (formulated product for the total area).

The research methodology used to collect and analyze data of this experiential learning activity was qualitative. Analysis of the value of the laboratory was determined through a questionnaire given to students in the laboratory when the weed management recommendation report was due. Seventeen statements were rated on a scale of 1 to 5, with 1 being strong agreement, 3 as neutral, and 5 as strong disagreement (Table 2.1). Students were asked to identify their major as Agronomy or other, and if they were in Agronomy, to list their option. Multiple years of data were collected from students which took part in this learning activity during Fall 2004, 2005, and 2006 semesters (n = 54). The correlation procedure of SAS (2002) was used to determine associations between student perceptions of the experiential learning activity as a valuable activity and other evaluation responses (Table 2.2). A questionnaire was also completed by instructors of Weed Science to determine their assessment of the activity.

Activity #2: Undergraduate Research Assistantships (URAs)

Learning Farm URAs assisted with day-to-day field operations and were assigned an experimental learning project under a professor or graduate student mentor in the Department of Agronomy. The population of this study consisted of all URAs (n = 5) which completed a research project focused on weed science at the Learning Farm from September 2003 to December 2006. An ideal sample would have included a diversity of undergraduate students from various agricultural backgrounds, genders, races, and countries of origin. However, due to limited students and project opportunities, students' projects were based on research interests and the availability of research projects.

Five students completed weed science-based research projects. Project titles included "Correlation of Site-Specific Soil Properties and Growth Patterns of Winter Annual/Biennial Weed Populations," "Velvetleaf Emergence at Various Depths, Soil Temperatures, and Ground Cover," "Response of Teff to Various Herbicides in Eastern and Western Kansas," "Competitiveness of Volunteer Teff in Corn and Grain Sorghum," and "Glyphosate Dose Response of Hophornbeam Copperleaf." These projects were selected because they either were of interest to the student or professor, currently had funding, or had potential of being funded, and could be completed in a time frame of two semesters.

Student evaluations of their interests and the value of their research experience were conducted thru questionnaires completed before initiation of the project, following the completion of the project, and following graduation (Table 2.3). URAs also were asked to produce either a poster or oral report that was presented by the URA at Agronomy Department

Seminars and regional meetings. Reports consisted of a 15 minute oral presentation and/or scientific poster, which included a literature review, materials and methods, data analysis, and results and discussion. Students were also encouraged to examine what they accomplished, how they would change their research project if they were to conduct the experiment again, and to suggest future research projects on their topic.

Students were asked to rate the experience on a scale of 1 to 5 as previously described. The purpose of the pre-project selection questionnaire was to set a base-line and to determine what the student expected to gain from the research experience. The post-project completion questionnaire explored the students' perceptions about the development and procedure of completing a research project, and their perceptions regarding the educational value of the experience. These questions also attempted to discern the knowledge gained from completing a research project and self-revelation of students' attitudes toward agronomy, weed science, and research. Student's major and agronomy option were noted on the questionnaires. Correlations between student's response of the value of experiential learning activity following completion of the study and the response of other post-project evaluation questions was done using correlation procedure of SAS (SAS 2002). Additionally, for those URAs who graduated from KSU, a post-graduation survey was presented to them to answer how this experience helped them in their future endeavors.

RESULTS AND DISCUSSION

Since February 2004, the Learning Farm has been visited by 934 undergraduate students attending KSU. The majority of these students were enrolled in one of the four classes that conduct hands-on learning laboratories every semester at the Learning Farm. Additional students that visited the Learning Farm either served as URAs, student hourly workers, or were a member of the KSU Collegiate Crop, Soil, or Weed Team. Students completed questionnaires following their visit to the Learning Farm and from those questionnaires it was noted that more than 98% of students visiting the Learning Farm were in the College of Agriculture and of those 45% were obtaining a Bachelor of Science degree in Agronomy. These figures were important in the development and focus of experiential learning activities at the Learning Farm.

Activity #1: Developing a Weed Management Recommendation

Students were allowed to choose their own groups to scout fields and complete the weed management recommendation exercise. This resulted in diverse groups with the majority of groups having two students majoring in Agronomy and one student majoring in Agricultural Business, Agricultural Education, or Horticulture. Groups showed a range of skills as they scouted the fields, as most groups not only identified the weeds present but also eluded to other issues, such as disease, insect, and possible soil fertility problems. The additional information collected by the groups was included in their report of weed management recommendations if they deemed the information important to the success of their weed management program.

The selected fields in 2004 and 2005 were all in no-tillage systems, and in 2006 two of the three fields were in a no-tillage system. Most groups provided additional tactics that would be part of a successful no-tillage cropland system. Field sizes ranged from 4 to 10 hectares. All groups elected to collect data from at least ten 1 m^2 areas within each field as a baseline to develop appropriate weed management recommendation.

There were no differences in student responses by varying major or Agronomy option in the questionnaire (data not shown). The standard deviations for student responses to the statements were relatively large as compared to the means, indicating a wide range of responses among the students. The majority of the students, regardless of major or Agronomy option, were positive in the "value of the activity", giving it a rating of 1.3 (Table 2.1). They gave a similar rating to the assignment's ability to increase their understanding of herbicide recommendations.

The strengths of the assignment were improved ability to receive information through observation and improved critical thinking skills. Students also indicated that the assignment required effective time management, a trait often cited by employers as being critically important, but generally lacking in recent college graduates (Andelt et al. 1997). Interestingly, students were neutral as to whether the final report provided a good review of the class or to the benefit of peer interaction with the exercise, which were two of the major goals of the assignment. A possible explanation of the low rating for peer interactions is that groups had trouble organizing all of their members to meet at a specific time in order to visit and scout the fields outside the allotted laboratory time period.

Five significant correlation coefficients showed relationships between students viewing the assignment as valuable and the other questions (Table 2.2). Value of the activity was positively correlated to increased understanding of herbicide recommendations after completing the activity, requiring effective time management skills, and improving one's critical thinking skills. Students viewing the assignment as valuable also thought the final report provided a good review of Weed Science and indicated they would be interested in more hands-on learning in their educational program.

Instructors noted that this activity was quite successful at demonstrating the practices and procedures required to make an appropriate weed management recommendation. The timing in Fall semester and two-week duration of the experiential learning activity, however, could be more beneficial to students if it was performed during the spring or summer semesters, when weeds are growing more actively. Students struggled at times with the complexity of the assignment, and with the time management required to complete the project on time as a group. Out of the 54 students that completed the survey, four were given additional time to complete the assignment or to reexamine a particular field. Areas that need improvement are expanding the weed identification ability of the students and the transfer of basic herbicide application procedures and their timings from class to field.

The majority of the students correctly identified the majority of the weeds in the field utilizing weed identification skills they learned in class or with the aid of the WeedVIEW® feature in WeedSOFT®. Groups of students often provided more than the minimum data on their scouting forms, and all but one group used a scouting pattern that was suggested in class. The final WeedSOFT® recommendations and students' choice of herbicide(s) or rate(s) were in most cases adequate for the control of the weeds within the fields. Most students lost points on the final report due to mistakes in calculations and conversions of actual to active product amounts.

Activity #2: Undergraduate Research Assistantships (URAs)

URAs at the Learning Farm were involved with studies in the discipline of weed science. Research projects contained multiple steps in the examination of a particular crop/weed/herbicide problem. Selected projects often included both greenhouse and field research, and occasionally included a laboratory or growth chamber component to the research. Students also had the opportunity of working with other URAs or fellow students on their research project and on having others help them with their project. Interestingly, only two of the five URAs conducting weed science research projects were in Agronomy as a major and one was in a minor in Agronomy. There were, however, no differences in students' responses based on choice of major or Agronomy option (data not shown).

Most students were neutral as to their interest in weed science before the initiation of the project. Examining the pre-project evaluation, the standard deviations for interest in agronomy and interest in research were relatively small (Table 2.3). The majority of students were enrolled in a weed science class before acceptance of an URA position, but had never considered the value of completing a research project in weed science for their educational experience. Post-project evaluation showed that the research was a valuable activity, with a rating of 1.2 (Table 2.3). A similar rating was obtained in the improvement of critical thinking skills. Students, however, were more neutral of whether the project improved their ability to present research data and write more clearly. This may be because students provided only shortened explanations of their research and were not required to complete a full journal article. Since the initiation of the weed science projects with the Learning Farm, two of the URAs have graduated. The post-graduation evaluations showed URAs have a heightened interest in agronomy, weed science, and research. The value of their research experience received a rating of 1.0 (Table 2.3).

Correlation analysis indicated that students who viewed the research experience as valuable thought it improved their abilities in four of the six skill categories associated with the experiential learning activity (Table 2.4). However, significant correlations were not detected between perception of completing a research project as valuable and increased ability to receive information effectively through observation and improved ability to write clearly. The lack of correlation for these two outcomes most likely resulted from lower ratings than the other outcomes by all students (Table 2.3). Correlations were significant between the assessment of the value of completing a research project and the transfer of concepts learned in this activity to other situations and the activity proving to be beneficial following graduation.

CONCLUSIONS

Properly facilitated learning through direct meaningful experiences is known to have direct and lasting benefits to the learner (Conrad and Hedin 1995; Jerstedt 1980). Students more easily recall information learned through first-hand experiences rather than through activities in which they could do not have an active roll. As expressed by the students, their experiences included not only learning the course content or research procedure, but also the application of that content through actual hands-on practice and the preparation of a final report. Students' assessments of these learning activities indicated that both assignments related to experiential learning increased their problem-solving and critical thinking skills.

SOURCES OF MATERIALS

[1]WeedSOFT®, University of Nebraska, P.O. Box 830915, Lincoln, NE 68583-0915.

[2]Chemical Weed Control for Field Crops, Pastures, Rangeland, and Noncropland, Report of Progress 977. Kansas State University Agricultural Experiment Station and Cooperative Extension Service, 2004 Throckmorton Plant Science Center, Manhattan, KS 66506-5501.

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Table 2.1 Student assessment and instructor perceptions of weed management recommendation learning activity.[a,b]

Statement	Mean	Standard deviation
Student Assessment		
This was a valuable activity.	1.3	0.71
The training I received provided knowledge to make accurate weed control recommendations.	1.4	0.62
I have an increased understanding of weed management after completing this activity.	2.5	0.83
I have an increased understanding of herbicide recommendations after completing this activity.	1.4	0.63
I have an increased understanding of WeedSOFT® after completing this activity.	2.5	0.86
I can transfer the concepts learned in this activity to other situations.	2.4	1.05
This activity improved my ability to receive information effectively through observation.	1.7	0.70
This activity provided insight into weed control I never before considered.	2.4	0.97
This activity improved my critical thinking skills.	1.5	0.67
I would be interested in more hands-on learning activities.	1.2	0.69
Peer interaction in this learning activity was beneficial.	3.3	1.32
Completion of this activity required effective time management.	1.9	0.73
The final report provided a good review of Weed Science (AGRON 330).	3.1	0.98
Instructor Perceptions		
Students correctly identified the weeds present in the field.	1.7	0.99
Scouting pattern was similar to patterns suggested in early laboratory section.	1.3	0.62
WeedSOFT® recommendations were accurate.	2.0	1.16
Students' choice of herbicide application and rate was adequate.	2.0	1.16

[a]Responses to each statement were rated on a scale of 1 to 5. 1 = strongly agree, 3 = neutral, and 5 = strongly disagree.
[b]Sample size = 54.

Table 2.2. Correlations between student assessment of the weed management recommendation learning activity as a valuable activity (the first statement in Table 2.1) and other evaluating statements.

Statement	Coefficient of correlation (*r*)	P > r
The training I received provided knowledge to make accurate weed control recommendations.	0.02	0.643
I have an increased understanding of weed management after completing this activity.	0.29	0.078
I have an increased understanding of herbicide recommendations after completing this activity.	0.67	0.004
I have an increased understanding of WeedSOFT® after completing this activity.	0.09	0.452
I can transfer the concepts learned in this activity to other situations.	0.24	0.099
This activity improved my ability to receive information effectively through observation.	0.18	0.183
This activity provided insight into weed control I never before considered.	0.12	0.263
This activity improved my critical thinking skills.	0.73	<0.001
I would be interested in more hands-on learning activities.	0.88	<0.001
Peer interaction in this learning activity was beneficial.	0.02	0.624
Completion of this activity required effective time management.	0.51	0.034
The final report provided a good review of Weed Science (AGRON 330).	0.37	0.041

Table 2.3. Pre-project selection, post-project completion, and post-graduation evaluations of undergraduate research assistantships focused on weed science at the Agronomy Learning Farm.[a]

Statement	Mean	Standard deviation
Pre-Project Evaluation[b]		
Interest in agronomy	1.6	0.55
Interest in weed science	2.4	0.89
Interest in research	1.0	0.00
This activity will prove to be beneficial following graduation.	2.0	1.00
I expect this project to increase my problem-solving and critical thinking ability.	2.0	0.71
Post-Project Evaluation[b]		
This was a valuable activity.	1.2	0.45
This activity improved my ability to receive information effectively through observation.	1.8	0.84
This activity improved my ability to analyze research data.	1.8	0.84
This activity improved my ability to write clearly.	2.4	1.14
This activity improved my ability to present research data.	2.0	1.00
This activity improved my critical thinking skills.	1.2	0.45
Completion of this activity required effective time management.	1.8	0.84
I can transfer the concepts learned in this activity to other situations.	1.6	0.55
This activity will prove to be beneficial following graduation.	1.4	0.55
Post-Graduation Evaluation[c]		
Interest in agronomy.	1.0	0.00
Interest in weed science.	1.0	0.00
Interest in research.	1.0	0.00
This was a valuable activity.	1.0	0.00

[a]Responses to each statement were rated on a scale of 1 to 5. 1 = strongly agree, 3 = neutral, and 5 = strongly disagree.
[b]Sample size = 5.
[c]Sample size = 2.

Table 2.4. Correlations between student assessment of the undergraduate research assistantships focused on weed science as a valuable activity (the first statement under post-project evaluation in Table 2.3) and other evaluating statements.

Statement	Coefficient of correlation (*r*)	P > r
This activity improved my ability to receive information effectively through observation.	0.13	0.581
This activity improved my ability to analyze research data.	0.80	<0.001
This activity improved my ability to write clearly.	0.29	0.222
This activity improved my ability to present research data.	0.56	0.015
This activity improved my critical thinking skills.	0.73	<0.001
Completion of this activity required effective time management.	0.64	0.005
I can transfer the concepts learned in this activity to other situations.	0.41	0.081
This activity will prove to be beneficial following graduation.	0.61	0.007

GENERAL INFORMATION

Scout(s):	Sketch of Field: ↑N
Date:	
Time:	
Field ID:	
Acres:	
Crop:	
Previous Crop:	

mark all area of the field scouted

CROP

Crop growth stage:	Crop height:
Soil conditions:	
Weather conditions:	

FIELD

Disease	Sampling Unit	Visual % infection per survey stop	Total	Average Damage
1.				
2.				
3.				
Insect	**Sampling Unit**	**#pests/damaged plants per survey stop**	**Total**	**Average Damage**
1.				
2.				
3.				
4.				
Weed	**Sampling Unit**	**N=None, VL=Very low, L=Low, M=Moderate, H=High, VH=Very High**	**Growth Stage**	**Average Height**
1.				
2.				
3.				
4.				
5.				
6.				
Soil Sample: *Y or N*		Nutrient Deficiency: *N or P or K or Micro*		
Nematode Sample: *Y or N*				

Additional Comments:

Figure 2.1. Scouting form for the Agronomy Learning Farm.

CHAPTER 3 - Efficacy of Sulfonylurea Herbicides when Tank Mixed with Mesotrione

ABSTRACT

Experiments were conducted in greenhouse and field to evaluate efficacy of various sulfonylurea herbicides applied with mesotrione or mesotrione + atrazine. The addition of mesotrione or mesotrione + atrazine to sulfonylurea herbicides had no adverse effects on the control of large crabgrass or velvetleaf in a controlled environment. Tank mixing mesotrione or mesotrione + atrazine with nicosulfuron or foramsulfuron, however, antagonized nicosulfuron and foramsulfuron control of green foxtail and shattercane. Field experiments conducted in 2004 and 2005 also indicated that addition of mesotrione + atrazine to a sulfonylurea herbicide decreased herbicidal efficacy on green foxtail, yellow foxtail, and shattercane, compared with the sulfonylurea herbicide applied alone. In addition, increasing mesotrione application from 53 to 105 g ha^{-1} decreased herbicidal efficacy of sulfonylurea herbicide in the tank mix on selected grass species. This research showed that the addition of mesotrione to sulfonylurea herbicides will result in decreased efficacy of sulfonylurea herbicides on green foxtail, yellow foxtail, and shattercane. The addition of atrazine to the tank mix or an increased mesotrione rate will further decrease herbicide efficacy of sulfonylurea herbicides on shattercane and foxtail species.

Nomenclature: Atrazine; foramsulfuron; mesotrione; nicosulfuron; rimsulfuron; green foxtail, *Setaria viridis* (L.) Beauv., SETVI; large crabgrass, *Digitaria sanguinalis* (L.) Scop., DIGSA;

shattercane, *Sorghum bicolor* (L.) Moench, SORVU; velvetleaf, *Abutilon theophrasti* Medicus, ABUTH; yellow foxtail, *Setaria glauca* (L.) Beauv., SETLU.

Key words: Antagonism**,** HPPD-inhibiting herbicides, triketone herbicides.

INTRODUCTION

Corn (*Zea mays* L.) is grown on more hectares than any other crop in the United States, with more than 30 million hectares planted annually to corn since 2002 (USDA 2006). The development of corn and final grain yield can be severely influenced by numerous abiotic and biotic factors, including weeds. The USDA (2004; 2006) reports that producers primarily rely on herbicides to control weeds in corn, with more than 95% of the corn planted in the United States receiving some type of herbicide treatment. Producers have traditionally used soil-applied herbicides to minimize weed emergence and early-season growth in corn. Concern over herbicide residues in the environment, development of herbicide resistant weeds, and availability of effective postemergence (POST) applied herbicides recently has led to more reliance on POST herbicides to control weeds (Sweat et al. 1998).

Mesotrione is one of the most widely used herbicides in corn and was applied to 20% of U.S. corn hectares in 2005 (USDA 2006). Mesotrione is a relatively new, selective, soil- and foliar-applied herbicide labeled for corn (Mitchell et al. 2001). Mesotrione applied preemergence (PRE) controlled numerous broadleaf weed species, including several morningglory species (*Ipomoea* spp.), smooth pigweed (*Amaranthus blitoides*), and velvetleaf (*Abutilon theophrasti*) (Ohmes et al. 2000; Stephenson et al. 2004). In addition, grass species such as large crabgrass (*Digitaria sanguinalis*), barnyardgrass (*Echinochloa crus-galli*), and broadleaf signalgrass (*Brachiaria platyphylla*) were suppressed with PRE mesotrione applications. Postemergence applications of mesotrione effectively control *Amaranthus* spp., prickly sida (*Sida spinosa*), and velvetleaf, but have limited activity on grasses (Abendroth et al. 2006; Creech et al. 2004; Stephenson et al. 2004). Therefore, atrazine and/or sulfonylurea herbicides are often tank mixed with POST applications of mesotrione for additional grass control in corn.

Tank mixing two or more herbicides is a common practice that is increasingly used in most agronomic crops to control a wide spectrum of weeds, reduce production cost, and/or prevent the development of herbicide-resistant weeds (Zhang et al. 1995). This approach is based on the assumption that herbicides act independently when applied simultaneously. Previous research, however, has demonstrated that herbicides may interact, before or after entering the plants, and the outcome of the interaction could be synergistic, additive, or antagonistic (Hatzios and Penner 1985; Olson and Nalewaja 1981). It would be ideal to select herbicide combinations that have synergistic effects on weeds and/or antagonistic effects on crops. In practice, though, combinations of herbicides are usually chosen without prior knowledge of the possible consequences of the interactions, and research has shown that interactions between herbicides were antagonistic more frequently than synergistic (Zhang et al. 1995).

Antagonistic interactions occur more frequently when the target plants are monocot rather than dicot, and in the Compositae, Gramineae, or Leguminosae families (Zhang et al. 1995). Previous research has shown reduced control of grasses when broadleaf herbicides are mixed with POST graminicides such as aryloxyphenoxypropionates and cyclohexanediones or certain imidazolinones or sulfonylurea herbicides (Hart et al. 1992; Hart and Wax 1996; Mueller et al. 1989; Myers and Coble 1992). Applications of imazethapyr at 18 g ha^{-1} reduced giant foxtail (*Setaria faberi*) dry weight by 83%; but adding 36 g ha^{-1} clethodim to imazethapyr decreased giant foxtail dry weight by only 78% (Nelson et al. 1998). Similarly, Cantwell et al. (1989) reported reduced giant foxtail control when imazethapyr was tank mixed with sethoxydim. Hart and Penner (1993) reported that atrazine significantly reduced translocation of primisulfuron to meristematic sinks in giant foxtail. Additional research has indicated that tank mixing sulfonylurea herbicides with atrazine can result in an 18% reduction in johnsongrass (*Sorghum halepense*) control compared to sulfonylurea herbicide applied alone (Damalas and Eleftherohorinos 2001).

In 2002, we received reports that green foxtail (*Setaria viridis*) and shattercane (*Sorghum bicolor*) control were reduced when mesotrione was applied in combination with sulfonylurea herbicides. The addition of atrazine to mesotrione, which has been shown to have a synergistic effect on broadleaf species (Abendroth et al. 2006), was reported to further decrease grass control by the sulfonylurea herbicides. The objectives of this research were to determine interactions between mesotrione and sulfonylurea herbicides applied on selected weed species and to determine if addition of atrazine to the mesotrione and sulfonylurea herbicide mixture alters herbicide efficacy.

MATERIALS AND METHODS

Plant Materials

Green foxtail, yellow foxtail (*Setaria glauca*), large crabgrass, shattercane, Palmer amaranth (*Amaranthus palmeri*), and/or velvetleaf were used in various sections of this study. These weeds are commonly found in corn fields throughout the Midwestern United States. They are normally controlled or suppressed by the sulfonylurea herbicides, mesotrione, and/or mesotrione + atrazine.

Dose Response Study

Green foxtail, large crabgrass, shattercane, and velvetleaf were grown in 11-cm diam. containers filled with a 1:1 (vol vol^{-1}) mixture of sand and Morrill loam soil (fine-loamy, mixed, mesic Typic Argiudolls), with a pH of 7.2 and 1.8% organic matter (OM). Greenhouse conditions were 26/24 ± 3 C day/night temperatures, with a 16/8 hour day/night period. The supplemental light intensity was 84 µmol m^{-2} s^{-1} photosynthetic flux. Sub-irrigation was used to maintain sufficient moisture. A commercial fertilizer[1] solution containing 0.40 mg L^{-1} nitrogen, 0.34 mg L^{-1} phosphorus, and 0.33 mg L^{-1} potassium was used to supply nutrients as needed by the plants. Plants were thinned to two plants per container 1 wk before herbicide application.

Green foxtail, large crabgrass, shattercane, and velvetleaf seedlings were treated with 0.25X, 0.5X, 0.75X, and 1X the use rates of mesotrione, mesotrione + atrazine, foramsulfuron, nicosulfuron, and rimsulfuron. The use rates were 757, 105, 37, 35, and 18 g ha^{-1} for atrazine, mesotrione, foramsulfuron, nicosulfuron, and rimsulfuron, respectively. In addition, mesotrione or mesotrione + atrazine were applied in combination with foramsulfuron, nicosulfuron, or rimsulfuron. For example, 0.25X mesotrione was applied with the 0.25X rate of foramsulfuron, nicosulfuron, and rimsulfuron, whereas the 0.5X mesotrione was applied with the 0.5X rate of foramsulfuron, nicosulfuron, or rimsulfuron. The study included a non-treated control.

Herbicides were applied with a bench-type sprayer[2] equipped with 80015LP[3] spray tip. The sprayer was calibrated to deliver 187 L ha^{-1} at 138 kPa. All treatments included crop oil concentrate[4] (COC) at 1.0% vol vol^{-1} plus urea-ammonium nitrate (UAN) at 2.5% vol vol^{-1} as recommended on herbicide label[5]. Control plants, which received no herbicide treatment, were treated with water plus COC plus UAN.

The experiment was a randomized complete block design with four replications, and the experiment was repeated twice. Visual ratings of percent of plant control were made at 7 and 21 days after treatment (DAT), based on a scale of 0 to 100%, where 0% equals no control and 100% equals complete control. At 21 DAT, plant height was measured and then plants were harvested at ground level and dried at 70 C for 96 h to a constant weight.

Herbicide Interaction Study

Field experiments were conducted at the Kansas State University Agronomy Department fields at Ashland Bottoms – located 8 km south of Manhattan, KS, and at Rossville – located 66 km east of Manhattan, KS, in 2004 and 2005. The soil type at Manhattan was a Reading silt loam (fine-silty, mixed, superactive, mesic Pachic Argiudolls) with a pH of 6.3 and 2.2% OM in both 2004 and 2005. At Rossville, the soil type was a Eudora silt loam with a pH of 6.5 and 1.7% OM in 2004 and a pH of 6.6 and 1.6% OM in 2005. The Manhattan site was under dryland production whereas a sprinkler irrigation system was used at Rossville.

The experiments were a randomized complete block design with four replications. Plots were 3.1 by 7.6 m. Corn hybrid 'DKC53-34RR' was planted in 0.76-m rows at 60,000 seeds ha^{-1} and 74,500 seeds ha^{-1} at Manhattan and Rossville, respectively, on April 21, 2004, and April 26, 2005. Green foxtail, yellow foxtail, and shattercane seed were sown perpendicular to the corn rows immediately after corn planting at both sites. Natural infestations of additional weeds were also present within the fields; Palmer amaranth was the primary broadleaf weed at Manhattan in 2004 and 2005 and at Rossville in 2004. Herbicides were applied with a CO_2 pressurized backpack sprayer with XR8002[3] flat fan nozzle tips calibrated to deliver 140 L ha^{-1} at a pressure of 117 kPa.

Herbicide treatments included mesotrione at 53 or 105 g ha^{-1}, applied with or without atrazine, and in combination with the use rate of foramsulfuron, nicosulfuron, nicosulfuron + rimsulfuron, primisulfuron, and primisulfuron + prosulfuron. Atrazine, foramsulfuron, nicosulfuron, nicosulfuron + rimsulfuron, primisulfuron, and primisulfuron + prosulfuron use rates were 757, 37, 35, 26 + 13, 40, and 30 + 10 g ha^{-1}, respectively. In addition, foramsulfuron, nicosulfuron, nicosulfuron + rimsulfuron, primisulfuron, and primisulfuron + prosulfuron were each applied alone. A non-treated control plot was included for comparison. All herbicide treatments included COC plus UAN, as previously discussed.

Visual ratings of crop injury and weed control were taken 7, 21, and 49 DAT. Visual ratings were based on a scale of 0 to 100%, as previously described. Heights of green foxtail and shattercane were measured at 49 DAT. Dry weight of green foxtail and shattercane were determined by harvesting plants in 1 m^2 area and dried at 70 C for 96 h to a constant weight.

Data Analysis

Interactions were determined by the Colby multiplicative method (Colby 1967). Expected responses for the combinations of mesotrione +/- atrazine with foramsulfuron, nicosulfuron, nicosulfuron + rimsulfuron, primisulfuron, primisulfuron + prosulfuron, and rimsulfuron were calculated as:

Expected (% control) = observed (control A) + observed (control B) –

[(observed (control A)(observed (control B)) / 100]

where "*A*" is replaced with mesotrione or mesotrione + atrazine observed control ratings and "*B*" is replaced with foramsulfuron, nicosulfuron, nicosulfuron + rimsulfuron, primisulfuron, primisulfuron + prosulfuron, or rimsulfuron observed control ratings. The observed values for green foxtail, large crabgrass, Palmer amaranth, shattercane, velvetleaf, and yellow foxtail control were compared with the expected values by using a Least Significant Difference (LSD) test at P = 0.05. The following formula was used to calculate the LSD:

$$LSD = t_{(a/2,\ df)} * \text{square root } \{\text{mean square error } [1 + (1 - (\text{lsmean}_{\text{ herbicide A}}) / 100)^2 + (1 - (\text{lsmean}_{\text{ herbicide B}}) / 100)^2]\}$$

The formula is based on the delta method, which is a mathematical procedure for finding the variance of a function of normal random variables. An observed response was determined to be antagonistic when it was less than the expected response level by at least the LSD value. If the difference between the two values was not significant, then the combination was considered additive. All data were tested for homogeneity of variances, and were subjected to analysis of variance, and means were separated by using an LSD at P = 0.05.

RESULTS AND DISCUSSION

Visual symtomology of broadleaf weed species treated with mesotrione or sulfonylurea herbicides was similar in both greenhouse and field studies. Palmer amaranth or velvetleaf treated with mesotrione at 105 g ha^{-1} showed severe bleaching of developing leaves within four days of application. Leaf necrosis of broadleaf weed species treated with mesotrione was apparent 10 to 15 DAT. Leaves of velvetleaf and Palmer amaranth treated with a sulfonylurea herbicide were chlorotic with red veins 7 to 10 DAT, followed by severe necrosis of all plant tissue. Tank mixing mesotrione with a sulfonylurea herbicide resulted in plants with a combination of injury symptoms as described.

Intensity of mesotrione or sulfonylurea herbicide injury symptoms on grass species varied, depending on rates. Foxtail species and shattercane showed slight bleaching of developing leaves within the first week after mesotrione application, but plants recovered by 14 DAT. Large crabgrass showed severe bleaching by 5 DAT, followed by necrosis 14 DAT. Sulfonylurea herbicide injury symptoms on foxtail species and shattercane were reddening of leaves and plant stunting by 7 DAT, and symptoms intensified over-time. At 14 DAT, foxtail and shattercane plants were chlorotic, with some necrosis. Rimsulfuron resulted in the most severe injury of the sulfonylurea herbicides on all grass species, followed by foramsulfuron or nicosulfuron, which had similar severities of injury. Tank mixing mesotrione with sulfonylurea herbicides resulted in less than expected reddening, chlorosis, and stunting of shattercane and foxtail species.

Dose Response Study

Control ratings in the greenhouse for green foxtail, large crabgrass, shattercane, and velvetleaf were higher than expected after a mesotrione treatment. Previous research, however, as indicated that grass species are often more susceptible to herbicides when grown in a controlled environment, compared with being grown in the field (Swanton et al. 1996). Green foxtail control with mesotrione at the use rate was 23% at 21 DAT (Table 3.1). These results are in agreement with earlier reports that control of a similar species was poor with mesotrione (Armel et al. 2003). The addition of atrazine to mesotrione at the use rate increased the control of green foxtail by 53%, compared with using mesotrione alone. Green foxtail control with foramsulfuron, nicosulfuron, or rimsulfuron varied, depending on herbicide rate. The range of green foxtail control with foramsulfuron, nicosulfuron, and rimsulfuron was 57 to 88%, 48 to 87%, and 69 to 93%, respectively, at 21 DAT. Foramsulfuron, nicosulfuron, and rimsulfuron at the use rate reduced green foxtail height by 18, 18, and 22 cm, respectively (data not shown).

Green foxtail biomass was reduced substantially by sulfonylurea herbicides at use rates, compared with untreated control.

Tank mixing mesotrione with sulfonylurea herbicides resulted in less green foxtail control at 7 and 21 DAT, compared with results from the sulfonylurea herbicide applied alone. Biomass of green foxtail treated with mesotrione and foramsulfuron or nicosulfuron at the use rate was 50 and 40% greater than when plants were treated with foramsulfuron or nicosulfuron alone, respectively (data not shown). The addition of atrazine to mesotrione and sulfonylurea herbicide tank mix further increased the antagonistic response of green foxtail to the herbicides. Mesotrione + atrazine and rimsulfuron resulted in less than expected control of green foxtail, with the average biomass of plants treated with the tank mix being 0.31 g, compared with 0.23 g biomass of plants treated with rimsulfuron alone.

Large crabgrass control with mesotrione ranged from 38 to 45% and 99 to 100% at 7 and 21 DAT, respectively (Table 3.1). Mesotrione + atrazine treatments resulted in control similar to that from mesotrione applied alone. Sulfonylurea herbicides, regardless of rate, resulted in less than 38% control of large crabgrass at 7 DAT. Foramsulfuron, nicosulfuron, and rimsulfuron control of large crabgrass at 21 DAT ranged from 25 to 53%, 1 to 5%, and 53 to 81%, respectively. Tank mixing mesotrione or mesotrione + atrazine with foramsulfuron, nicosulfuron, or rimsulfuron antagonized the activity of sulfonylurea herbicides, resulting in reduced control of large crabgrass 7 DAT. Large crabgrass control with mesotrione or mesotrione + atrazine and sulfonylurea herbicide at 21 DAT, however, was greater than 91%, with no antagonistic effect. The difference in presence of antagonistic interaction at 7 DAT and not at 21 DAT in large crabgrass could partly be explained by less observed injury symtomology from mesotrione when tank mixed with sulfonylurea herbicides at 7 DAT. The visual injury symtomology on large crabgrass at 21 DAT was primarily due to the mesotrione in the tank mix.

Shattercane control with mesotrione, mesotrione + atrazine, foramsulfuron, nicosulfuron, and rimsulfuron at the use rate was 61, 78, 97, 93, and 100%, respectively (Table 3.1). Applications of mesotrione with foramsulfuron or nicosulfuron resulted in 54 to 81% and 41 to 72% control of shattercane at 21 DAT, respectively. At 21 DAT, height of shattercane treated with mesotrione and foramsulfuron or nicosulfuron was 30 and 90% greater than the height of plants receiving an application of foramsulfuron or nicosulfuron alone, respectively. Mesotrione plus atrazine and foramsulfuron or nicosulfuron at the use rate resulted in 84 and 81% control of shattercane, respectively, whereas the expected control of the shattercane plants was 99%.

Velvetleaf control with mesotrione at 26, 53, 79, and 105 g ha^{-1} was 82, 94, 93, and 94%, respectively (Table 3.1). Mesotrione + atrazine, regardless of rate, provided greater than 96% control of velvetleaf. Sulfonylurea herbicide control of velvetleaf varied, depending on the herbicide. Foramsulfuron and rimsulfuron resulted in 82 and 98% control of velvetleaf, respectively, at the use rate, whereas nicosulfuron provided less than 35% control of the weed. Velvetleaf control at 7 DAT was significantly less than the expected value with a tank mix of mesotrione plus a sulfonylurea herbicide, indicating herbicide antagonism. Control ratings at 21 DAT, however, were not antagonistic. The presence of an antagonistic interaction at 7 DAT, but not at 21 DAT, in velvetleaf is due to less observed injury symtomology from mesotrione when tank mixed with sulfonylurea herbicides at 7 DAT. The visual injury symtomology on velvetleaf at 21 DAT, however, was primarily due to the mesotrione in the tank mix. Velvetleaf control with tank mixes of mesotrione + atrazine and foramsulfuron, nicosulfuron, or rimsulfuron were greater than 99% at 21 DAT.

Herbicide Interaction Study

Data were pooled across years because no treatment-by-year interaction occurred for response variables, including visual control, plant height, and dry weight. Corn injury by mesotrione in the form of leaf and whorl bleaching ranged from 0 to 7% at Manhattan and Rossville 7 DAT (data not shown). These results are in agreement with previous research that showed slight to 15% injury of corn after POST mesotrione (Johnson et al. 2002; Waltz et al. 1999). The addition of atrazine or sulfonylurea herbicides to mesotrione did not change the injury caused by mesotrione on corn plants. The bleaching symptomology caused by mesotrione was undistinguishable from untreated plants 14 DAT. In addition, there were no corn yield reductions at Manhattan or Rossville because of crop injury that coincided with herbicide injury symptoms.

Green foxtail control was minimal after an application of mesotrione at either 53 or 105 g ha^{-1}. Ohmes et al. (2000) also reported insufficient control of foxtail species with mesotrione. Foramsulfuron, nicosulfuron, and nicosulfuron + rimsulfuron, however, controlled more than 80 and 75% of green foxtail 21 DAT at Manhattan and Rossville, respectively (Table 3.2 & 3.3). Primisulfuron and primisulfuron + prosulfuron controlled 66 and 47% of green foxtail 21 DAT at Manhattan, respectively, and 61 and 68% of green foxtail at Rossville, respectively. The reduced efficacy of primisulfuron on green foxtail, compared with that of other sulfonylurea herbicides, may be partly attributed to decreased leaf absorption (Camacho and Moshier 1991) and less translocation than with other sulfonylurea herbicides (Hart and Penner 1993).

Mesotrione (53 g ha^{-1}) tank mixed with nicosulfuron or foramsulfuron controlled more than 80% of green foxtail 21 DAT at Manhattan (Table 3.2). Tank mixing mesotrione (105 g ha^{-1}) with foramsulfuron, nicosulfuron, nicosulfuron + rimsulfuron, primisulfuron, or primisulfuron

+ prosulfuron, however, resulted in less than expected control of green foxtail 21 DAT at Manhattan and Rossville. In addition, mesotrione decreased the efficacy of the sulfonylurea herbicides on green foxtail 49 DAT, indicating herbicide antagonism (Table 3.4). Mesotrione (105 g ha^{-1}) and nicosulfuron gave 23 and 16% less control than did the nicosulfuron alone treatment at Manhattan and Rossville 49 DAT, respectively. Green foxtail plant height and shoot biomass 49 DAT with mesotrione and sulfonylurea herbicide were greater than for plants treated with sulfonylurea alone. For example, tank mixing mesotrione (105 g ha^{-1}) with nicosulfuron resulted in green foxtail 5 cm taller, with a shoot biomass of 2.66 g greater, than plants treated with nicosulfuron alone (Table 3.4).

The addition of atrazine to mesotrione and sulfonylurea herbicide further antagonized the efficacy of sulfonylurea herbicides on green foxtail. Applications of mesotrione + atrazine (105 + 757 g ha^{-1}) with foramsulfuron or nicosulfuron controlled less than 66% of green foxtail 21 DAT at Manhattan and Rossville (Tables 3.2 & 3.3). At the Manhattan location, biomass of green foxtail treated with mesotrione + atrazine (105 + 757 g ha^{-1}) and foramsulfuron or nicosulfuron was 4.36 and 1.47 g greater than biomass of plants that received an application of foramsulfuron or nicosulfuron alone, respectively (Table 3.4).

Mesotrione applied at 53 and 105 g ha^{-1} controlled 25% of yellow foxtail 21 DAT at Manhattan and Rossville (Tables 3.2 & 3.3). Applications of foramsulfuron, nicosulfuron, or nicosulfuron + rimsulfuron, however, controlled more than 80% of yellow foxtail at both locations. Primisulfuron and primisulfuron + prosulfuron controlled 89 and 88% of yellow foxtail 21 DAT at Manhattan, respectively, and 77 and 78% of yellow foxtail at Rossville, respectively. Tank mixing mesotrione at 105 g ha^{-1} with foramsulfuron or nicosulfuron provided less than expected control of yellow foxtail 21 DAT at Manhattan and Rossville. The addition of mesotrione + atrazine to foramsulfuron or nicosulfuron increased the antagonistic response in yellow foxtail, compared with applications of mesotrione and foramsulfuron or nicosulfuron alone. Mesotrione + atrazine (105 + 757 g ha^{-1}) and foramsulfuron provided only 60% control of yellow foxtail 21 DAT at Manhattan, compared with 93% control when foramsulfuron was applied alone.

Shattercane control with mesotrione was less than 25 and 10% 21 DAT at Manhattan and Rossville, respectively (Tables 3.2 & 3.3). Sulfonylurea herbicides, however, provided at least 89 and 85% control of shattercane 21 DAT at Manhattan and Rossville, respectively. Tank mixing mesotrione and foramsulfuron or nicosulfuron resulted in less than expected control of shattercane 21 DAT at Manhattan. Similar antagonistic responses of shattercane were noticed with mesotrione + atrazine and sulfonylurea herbicide tank mix. At Rossville, shattercane height at 49 DAT after an application of mesotrione + atrazine and foramsulfuron or nicosulfuron was greater than 27 cm, whereas plants treated with foramsulfuron or nicosulfuron applied alone were approximately 1 cm in height (Table 3.5). Plant biomass was also greater after tank mix application of mesotrione + atrazine and foramsulfuron or nicosulfuron, compared with biomass when foramsulfuron or nicosulfuron was applied alone.

Palmer amaranth was the predominant broadleaf weed at Manhattan in 2004 and 2005 and at Rossville in 2004. Applications of mesotrione at 53 and 105 g ha^{-1} resulted in 81 and 87% Palmer amaranth control, respectively, 21 DAT at Manhattan (Table 3.2). Control ratings of Palmer amaranth 21 DAT, with the 53 g ha^{-1} mesotrione rate, were significantly less at Rossville, due to increased plant density (Table 3.3). The addition of atrazine to mesotrione application controlled more than 87% of Palmer amaranth plants 21 DAT at both Manhattan and Rossville. The sulfonylurea herbicides controlled less than 53 and 33% of Palmer amaranth plants at

Manhattan and Rossville, respectively. Poor Palmer amaranth control at both locations was likely due to resistant biotypes of the weed to herbicides that inhibit acetolactate synthesis (Dallas Peterson, personal communication).

Tank mixing mesotrione at 53 or 105 g ha^{-1} with a sulfonylurea herbicide resulted in an additive effect on the control of Palmer amaranth. There was a 5% increase in control of the weed after an application of mesotrione + atrazine and nicosulfuron, compared with control from either a single application of mesotrione or a tank-mix of mesotrione and nicosulfuron (Table 3.2). Similar results were reported at Rossville, with mesotrione + atrazine at 53 + 757 or 105 + 757 g ha^{-1} and nicosulfuron providing 91 and 95% control of Palmer amaranth at 21 DAT, respectively.

CONCLUSIONS

This research demonstrates that when mesotrione is tank mixed with a sulfonylurea herbicide, the herbicidal efficacy of the sulfonylurea herbicide on foxtail species and shattercane is significantly reduced. As seen in the herbicide interaction study, increasing the amount of mesotrione from 53 to 105 g ha^{-1} further reduced the herbicidal efficacy of the sulfonylurea herbicides on the grass species. Adding atrazine to the tank mix also resulted in a more pronounced decrease in control of weedy grass species. The reduction in weed control caused by this antagonism could possibly be alleviated by applying the broadleaf and grass weed herbicides sequentially, as discussed in previous studies (Croon and Merkle 1988; Hartzler and Foy 1983). This would require separate postemergence applications, which would be impractical and uneconomical for most farming situations. Increasing the rate of the sulfonylurea herbicide or decreasing the rate of mesotrione in the tank mix could also potentially reduce the antagonistic interaction for green foxtail and shattercane, but could result in increased crop injury or reduced broadleaf control.

SOURCES OF MATERIALS

[1] Miracle-Gro Plant Food, Scotts Miracle-Gro Products Inc., P.O. Box 606, Marysville, OH 43040.

[2] Research Track Sprayer SB-8. Devries Manufacturing, RR 1, Box 184, Hollandale, MN 56045.

[3] Spraying Systems Co., North Ave., Wheaton, IL 60188.

[4] Prime Oil, Terra International Inc., P.O. Box 6000, Sioux City, IA 53102-6000.

[5] Anonymous. 2001. Callisto® herbicide label. Greensboro, NC. Syngenta Crop Protection.

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Table 3.1. Visual control of green foxtail, large crabgrass, shattercane, and velvetleaf as affected by mesotrione or mesotrione + atrazine, applied alone or in combination with selected sulfonylurea herbicides, across a range of rates in greenhouse.[a]

		Green foxtail		Large crabgrass		Shattercane		Velvetleaf	
Herbicide[b]	Rate	7 DAT	21 DAT	7 DAT	21 DAT	7 DAT	21 DAT	7 DAT	21 DAT
	g ha^{-1}	% control[c]							
Mesotrione	26	5	0	38	99	18	15	11	82
	53	12	6	40	99	24	45	13	94
	79	17	16	44	100	28	49	15	93
	105	22	23	45	99	30	61	15	94
Foramsulfuron	9	16	57	21	25	19	78	33	62
	19	20	72	25	26	25	92	43	80
	28	22	82	27	39	35	95	42	77
	37	22	88	26	53	35	97	44	82
Nicosulfuron	9	20	48	7	1	22	54	11	21
	17	24	70	10	3	24	76	14	23
	26	23	81	9	4	23	84	17	26
	35	24	87	11	5	24	93	18	33
Rimsulfuron	5	26	69	28	53	41	100	50	94
	9	34	74	33	65	44	100	50	95
	13	34	86	33	66	52	100	53	95
	18	34	93	38	81	53	100	53	98
Mesotrione + atrazine	26 + 757	20	33	45	98	27	54	55	96
	53 + 757	20	48	45	99	31	68	58	98
	79 + 757	22	70	45	99	35	71	60	98
	105 + 757	25	76	45	99	40	78	62	98
Mesotrione +	26 + 9	15-	60	29-	99	17-	54-	26-	94
foramsulfuron	53 + 19	14-	63-	27-	99	21-	72-	40-	93
	79 + 28	15-	66-	26-	98	22-	76-	43-	95
	105 + 37	20-	71-	29-	99	25-	81-	43-	94
Mesotrione +	26 + 9	18-	54	32-	100	12-	41-	17-	89
nicosulfuron	53 + 17	19-	58-	38-	100	16-	58-	17-	88

	79 +26	23-	64-	42-	99	17-	70-	19-	91
	105 + 35	23-	68-	38-	100	20-	72-	21-	93
Mesotrione + rimsulfuron	26 + 5	15-	67	33-	91	34-	96	53-	99
	53 + 9	17-	73	33-	97	41-	100	52-	98
	79 + 13	26-	78-	32-	98	41-	100	55-	99
	105 + 18	31-	81-	34-	99	35-	100	54-	99
Mesotrione + atrazine + foramsulfuron	26 + 757 + 9	26-	56-	29-	98	28-	68-	45-	100
	53 + 757 + 19	26-	62-	29-	99	28-	74-	44-	100
	79 + 757 + 28	24-	67-	35-	99	31-	77-	52-	100
	105 + 757 + 37	22-	71-	35-	100	31-	84-	52-	100
Mesotrione + atrazine + nicosulfuron	26 + 757 + 9	23-	54-	37-	96	26-	67-	44-	100
	53 + 757 + 17	20-	64-	35-	98	31-	72-	44-	100
	79 + 757 + 26	25-	70-	37-	99	34-	74-	47-	100
	105 + 757 + 35	23-	74-	36-	100	34-	81-	53-	100
Mesotrione + atrazine + rimsulfuron	26 + 757 + 5	18-	69-	47-	99	25-	82-	46-	99
	53 + 757 + 9	21-	72-	52-	99	25-	93	50-	100
	79 + 757 + 13	18-	74-	52-	100	25-	95	53-	100
	105 + 757 + 18	18-	76-	56-	100	30-	95	50-	100
LSD (0.05)[d]		4	6	4	9	3	8	3	5

[a]Abbreviation: DAT, days after treatment.
[b]All treatments included 1% (vol vol^{-1}) crop oil concentrate and 2.5% (vol vol^{-1}) urea ammonium nitrate.
[c]A negative sign (-) indicates significant antagonism.
[d]Fishers Protected LSD (0.05) for comparing means within columns.

Table 3.2. Visual control of green foxtail, yellow foxtail, shattercane, and Palmer amaranth as affected by mesotrione or mesotrione + atrazine, applied alone or in combination with selected sulfonylurea herbicides, on corn at Manhattan, KS, in 2004 and 2005. Means were averaged across years.[a]

		Green foxtail		Yellow foxtail		Shattercane		Palmer amaranth	
Herbicide[b]	Rate	7 DAT	21 DAT	7 DAT	21 DAT	7 DAT	21 DAT	7 DAT	21 DAT
	$g\ ha^{-1}$	% control[c]							
Mesotrione	53	9	9	26	23	30	30	49	81
	105	14	9	35	19	31	26	64	87
Mesotrione + atrazine	53 + 757	21	14	43	34	30	29	68	87
Mesotrione + atrazine	105 + 757	46	50	48	63	53	57	69	92
Foramsulfuron	37	44	83	48	93	45	91	39	40
Nicosulfuron	35	40	81	46	82	49	90	53	53
Nicosulfuron + rimsulfuron	26 + 13	48	88	59	89	52	92	56	53
Primisulfuron	40	30	66	40	89	42	89	29	33
Primisulfuron + prosulfuron	30 + 10	32	47	55	88	50	91	39	54
Mesotrione + foramsulfuron	53 + 37	40	85	53	75-	41-	87	59	86
Mesotrione + nicosulfuron	53 + 35	42	81	56	86	46-	88	56	87
Mesotrione + nicosulfuron + rimsulfuron	53 + 26 + 13	45	83	60	86	52-	92	63	88
Mesotrione + primisulfuron	53 + 40	34	55-	52	86	43-	88	48	86
Mesotrione + primisulfuron + prosulfuron	53 + 30 + 10	34	50	44	77-	45-	87	53	83
Mesotrione + atrazine + foramsulfuron	53 + 757 + 37	35-	74-	54-	81-	45-	89	65	92
Mesotrione + atrazine + nicosulfuron	53 + 757 + 35	37-	75	58	83	50-	86	74	92
Mesotrione + atrazine + nicosulfuron + rimsulfuron	53 + 757 + 26 + 13	44-	82	53-	84	48-	90	68	92
Mesotrione + atrazine + primisulfuron	53 + 757 + 40	33-	61	54	73-	48-	87	69	92

Mesotrione + atrazine + primisulfuron + prosulfuron	53 + 757 + 30 + 10	36-	62	63	76-	48-	88	70	92
Mesotrione + foramsulfuron	105 + 37	37-	58-	46-	67-	46-	78-	52	87
Mesotrione + nicosulfuron	105 + 35	37-	73-	52-	59-	47-	74-	56	86
Mesotrione + nicosulfuron + rimsulfuron	105 + 26 + 13	38-	82	56-	83	46-	91	48	90
Mesotrione + primisulfuron	105 + 40	31	46-	43-	68-	43-	84	60	88
Mesotrione + primisulfuron + prosulfuron	105 + 30 + 10	28-	43	46-	55-	42-	80	53	85
Mesotrione + atrazine + foramsulfuron	105 + 757 + 37	31-	55-	43-	60-	46-	69-	64	87
Mesotrione + atrazine + nicosulfuron	105 + 757 + 35	39-	63-	43-	67-	49-	76-	69	92
Mesotrione + atrazine + nicosulfuron + rimsulfuron	105 + 757 + 26 + 13	42-	68-	55-	69-	47-	77-	72	92
Mesotrione + atrazine + primisulfuron	105 + 757 + 40	45-	62-	53-	82-	46-	82-	68	89
Mesotrione + atrazine + primisulfuron + prosulfuron	105 + 757 + 30 + 10	44-	60-	55-	63-	49-	75-	70	93
LSD (0.05)[d]		10	9	13	10	11	13	13	12

[a]Abbreviation: DAT, days after treatment.
[b]All treatments included 1% (vol vol^{-1}) crop oil concentrate and 2.5% (vol vol^{-1}) urea ammonium nitrate.
[c]A negative sign (-) indicates significant antagonism.
[d]Fishers Protected LSD (0.05) for comparing means within columns.

Table 3.3. Visual control of green foxtail, yellow foxtail, shattercane, and Palmer amaranth as affected by mesotrione or mesotrione + atrazine, applied alone or in combination with selected sulfonylurea herbicides, on corn at Rossville, KS, in 2004 and 2005. Means were averaged across years.[a]

		Green foxtail		Yellow foxtail		Shattercane		Palmer amaranth[d]	
Herbicide[b]	Rate	7 DAT	21 DAT	7 DAT	21 DAT	7 DAT	21 DAT	7 DAT	21 DAT
	g ha^{-1}	% control[c]							
Mesotrione	53	4	5	18	11	22	6	47	72
	105	12	3	25	5	29	7	63	90
Mesotrione + atrazine	53 + 757	15	16	46	42	39	40	75	94
Mesotrione + atrazine	105 + 757	18	30	43	47	41	43	77	95
Foramsulfuron	37	21	79	25	81	30	92	25	28
Nicosulfuron	35	21	81	29	87	35	93	26	30
Nicosulfuron + rimsulfuron	26 + 13	26	76	34	86	48	94	33	33
Primisulfuron	40	17	61	22	77	35	85	35	25
Primisulfuron + prosulfuron	30 + 10	14	68	25	78	48	94	15	20
Mesotrione + foramsulfuron	53 + 37	15	70	21-	76	26-	92	46	74
Mesotrione + nicosulfuron	53 + 35	19	77	24-	76	26-	92	60	69
Mesotrione + nicosulfuron + rimsulfuron	53 + 26 + 13	20	76	27-	79	30-	93	57	86
Mesotrione + primisulfuron	53 + 40	13	53	22-	70	29-	92	67	89
Mesotrione + primisulfuron + prosulfuron	53 + 30 + 10	16	44	25-	68	31-	90	73	91
Mesotrione + atrazine + foramsulfuron	53 + 757 + 37	23	70	47	71	36-	88	83	97
Mesotrione + atrazine + nicosulfuron	53 + 757 + 35	24	74	48-	81	37-	89	79	91
Mesotrione + atrazine + nicosulfuron + rimsulfuron	53 + 757 + 26 + 13	34	77	48-	76-	31-	94	76	95
Mesotrione + atrazine + primisulfuron	53 + 757 + 40	25	56	40-	83	37-	90	82	95
Mesotrione + atrazine + primisulfuron + prosulfuron	53 + 757 + 30 + 10	18	44-	45-	79	33-	87	80	94

Mesotrione + foramsulfuron	105 + 37	14-	50-	28-	60-	26-	84	63	84
Mesotrione + nicosulfuron	105 + 35	16-	66-	27-	55-	27-	88	61	91
Mesotrione + nicosulfuron + rimsulfuron	105 + 26 + 13	20-	74-	33-	81	30-	94	69	90
Mesotrione + primisulfuron	105 + 40	15-	53	25-	80	29-	89	61	90
Mesotrione + primisulfuron + prosulfuron	105 + 30 + 10	12-	40-	24-	58-	26-	90	60	85
Mesotrione + atrazine + foramsulfuron	105 + 757 + 37	18-	43-	45	66-	36-	71-	80	93
Mesotrione + atrazine + nicosulfuron	105 + 757 + 35	25-	66-	44-	72-	38-	81-	75	95
Mesotrione + atrazine + nicosulfuron + rimsulfuron	105 + 757 + 26 + 13	22-	57-	49	78-	46-	91	82	96
Mesotrione + atrazine + primisulfuron	105 + 757 + 40	26	56-	54	83	41-	87	85	95
Mesotrione + atrazine + primisulfuron + prosulfuron	105 + 757 + 30 + 10	18	39-	47	77	43-	78	84	93
LSD (0.05)[e]		10	13	14	15	11	13	22	19

[a]Abbreviation: DAT, days after treatment.
[b]All treatments included 1% (vol vol^{-1}) crop oil concentrate and 2.5% (vol vol^{-1}) urea ammonium nitrate.
[c]A negative sign (-) indicates significant antagonism.
[d]Data from 2004 only.
[e]Fishers Protected LSD (0.05) for comparing means within columns.

Table 3.4. Visual control, height, and shoot biomass of green foxtail and shattercane as affected by mesotrione or mesotrione + atrazine, applied alone or in combination with selected sulfonylurea herbicides, on corn 49 DAT at Manhattan, KS, in 2004 and 2005. Means were averaged across years.[a]

		Green foxtail			Shattercane		
Herbicide[b]	Rate	Control[c]	Height	Shoot biomass	Control[c]	Height	Shoot biomass
	g ha^{-1}	%	cm	g	%	cm	g
Untreated control	0	0	42	27.25	0	98	38.09
Mesotrione	105	9	39	24.00	29	66	28.66
Mesotrione + atrazine	105 + 757	50	29	8.91	40	48	18.28
Foramsulfuron	37	93	12	2.00	95	14	1.14
Nicosulfuron	35	85	10	3.83	89	13	1.34
Nicosulfuron + rimsulfuron	26 + 13	89	8	1.84	95	11	0.83
Primisulfuron	40	78	15	3.89	95	15	0.95
Primisulfuron + prosulfuron	30 + 10	67	15	6.57	97	8	0.75
Mesotrione + foramsulfuron	105 + 37	62-	20	5.29	67-	41	6.17
Mesotrione + nicosulfuron	105 + 35	62-	15	6.49	63-	38	6.99
Mesotrione + nicosulfuron + rimsulfuron	105 + 26 + 13	75-	15	4.38	90	20	1.46
Mesotrione + primisulfuron	105 + 40	47-	28	9.97	78-	25	5.48
Mesotrione + primisulfuron + prosulfuron	105 + 30 + 10	48-	26	9.09	78-	28	5.07
Mesotrione + atrazine + foramsulfuron	105 + 757 + 37	58-	21	6.36	67-	28	6.25
Mesotrione + atrazine + nicosulfuron	105 + 757 + 35	55-	22	5.30	56-	42	7.26
Mesotrione + atrazine + nicosulfuron + rimsulfuron	105 + 757 + 26 + 13	59-	21	7.19	66-	27	6.69
Mesotrione + atrazine + primisulfuron	105 + 757 + 40	64-	23	6.92	76-	32	5.00
Mesotrione + atrazine +	105 + 757	58-	24	7.01	68-	32	6.74

primisulfuron + prosulfuron	+ 30 + 10						
LSD (0.05)[d]		10	7	3.21	12	8	4.32

[a]Abbreviation: DAT, days after treatment.
[b]All treatments included 1% (vol vol^{-1}) crop oil concentrate and 2.5% (vol vol^{-1}) urea ammonium nitrate.
[c]A negative sign (-) indicates significant antagonism.
[d]Fishers Protected LSD (0.05) for comparing means within columns.

Table 3.5. Visual control, height, and shoot biomass of green foxtail and shattercane as affected by mesotrione or mesotrione + atrazine, applied alone or in combination with selected sulfonylurea herbicides, on corn 49 DAT at Rossville, KS, in 2004 and 2005. Means were averaged across years.[a]

		Green foxtail			Shattercane		
Herbicide[b]	Rate	Control[c]	Height	Shoot biomass	Control[c]	Height	Shoot biomass
	g ha^{-1}	%	cm	g	%	cm	g
Untreated control	0	0	35	11.23	0	88	43.01
Mesotrione	105	2	35	10.11	8	92	33.82
Mesotrione + atrazine	105 + 757	18	28	8.96	31	67	23.48
Foramsulfuron	37	89	13	2.78	99	1	0.13
Nicosulfuron	35	90	10	2.49	99	1	0.05
Nicosulfuron + rimsulfuron	26 + 13	90	11	2.94	99	1	0.05
Primisulfuron	40	73	19	4.67	99	1	0.11
Primisulfuron + prosulfuron	30 + 10	87	13	2.73	100	0	0.00
Mesotrione + foramsulfuron	105 + 37	44-	22	10.28	89	21	1.82
Mesotrione + nicosulfuron	105 + 35	74-	16	5.08	97	12	0.90
Mesotrione + nicosulfuron + rimsulfuron	105 + 26 + 13	75-	16	5.24	99	2	0.10
Mesotrione + primisulfuron	105 + 40	60-	21	8.04	97	4	0.24
Mesotrione + primisulfuron + prosulfuron	105 + 30 + 10	34-	24	9.07	98	2	0.36
Mesotrione + atrazine + foramsulfuron	105 + 757 + 37	40-	22	8.83	63-	39	7.90
Mesotrione + atrazine + nicosulfuron	105 + 757 + 35	64-	18	8.09	84-	27	3.84
Mesotrione + atrazine + nicosulfuron + rimsulfuron	105 + 757 + 26 + 13	58-	21	8.23	97	7	0.21
Mesotrione + atrazine + primisulfuron	105 + 757 + 40	48-	23	9.24	80-	24	3.69
Mesotrione + atrazine +	105 + 757	31-	27	9.56	74-	42	4.50

primisulfuron + prosulfuron	+ 30 + 10						
LSD (0.05)[d]		13	7	3.02	11	8	3.64

[a]Abbreviation: DAT, days after treatment.
[b]All treatments included 1% (vol vol^{-1}) crop oil concentrate and 2.5% (vol vol^{-1}) urea ammonium nitrate.
[c]A negative sign (-) indicates significant antagonism.
[d]Fishers Protected LSD (0.05) for comparing means within columns.

CHAPTER 4 - Mode of Antagonistic Effect of Mesotrione on Sulfonylurea Herbicide Efficacy

ABSTRACT

Studies were conducted to determine if absorption, translocation, or metabolism were the basis for the reduction in sulfonylurea herbicide efficacy on foxtail species when mesotrione was mixed with a sulfonylurea herbicide. Green foxtail and yellow foxtail plants were grown in the greenhouse and treated at the 4-leaf stage with ^{14}C-labeled nicosulfuron or rimsulfuron, applied alone or with mesotrione or mesotrione + atrazine. Absorption of nicosulfuron was greater in green foxtail and yellow foxtail 7 days after treatment (DAT) when applied alone, compared with absorption when mixing the herbicide with mesotrione or mesotrione + atrazine. Translocation of nicosulfuron to the treated tiller in green foxtail 7 DAT was 9% greater for nicosulfuron applied alone than when mixed with mesotrione or mesotrione + atrazine. Translocation of nicosulfuron in yellow foxtail, however, was similar when nicosulfuron was applied alone or in combination with mesotrione or mesotrione + atrazine. Mixing rimsulfuron with mesotrione did not reduce the absorption of rimsulfuron in green foxtail 7 DAT, but the addition of mesotrione + atrazine resulted in a 20% decrease in rimsulfuron absorption 7 DAT compared with absorption of rimsulfuron applied alone. Yellow foxtail absorption of rimsulfuron at 7 DAT was decreased by 11 or 20% when mixed with mesotrione or mesotrione + atrazine, respectively. Application of rimsulfuron alone resulted in 6% more herbicide being translocated to the treated tiller in green foxtail at 7 DAT, compared with an application of

mesotrione + atrazine and rimsulfuron. Translocation of rimsulfuron in yellow foxtail was similar when applied alone or in combination with mesotrione or mesotrione + atrazine. Nicosulfuron and rimsulfuron metabolism in foxtail species was similar when applied alone or in combination with mesotrione or mesotrione + atrazine.

Nomenclature: Atrazine; mesotrione; nicosulfuron; rimsulfuron; green foxtail, *Setaria viridis* (L.) Beauv., SETVI; yellow foxtail, *Setaria glauca* (L.) Beauv., SETLU.

Key words: Antagonism**,** HPPD-inhibiting herbicides, triketone herbicides.

INTRODUCTION

Nicosulfuron and rimsulfuron are sulfonylurea herbicides for postemergence weed control in corn (*Zea mays* L.). As members of the sulfonylurea family of herbicides, nicosulfuron and rimsulfuron have similar chemical structures, and usage rates, and have the same site of action. They inhibit acetohydroxyacid synthase (AHAS), also known as acetolactate synthase (ALS), which is the first enzyme unique to biosynthesis of the essential branched-chain amino acids leucine, valine, and isoleucine (Babczinski and Zelinski 1991; Ray 1984). The enzyme can either catalyze formation of acetohydroxybutyrate from pyruvate and α-ketobutyrate or synthesis of acetolactate from two molecules of pyruvate (Umbarger 1969). Corn and other tolerant species rapidly detoxify sulfonylureas to herbicidally inactive metabolites (Frear et al. 1991; Kreuz and Fonne-Pfister 1992; Mougin et al. 1991; Neighbors and Privalle 1990). The metabolism of sulfonylurea herbicides in certain annual and biennial weed species, however, is much slower and leads to phytotoxicity.

Previous reports have indicated that nicosulfuron and rimsulfuron provide control of many perennial and annual grasses, as well as certain broadleaf weed species. Nicosulfuron provided more than 80% control of giant foxtail (*Setaria faberi*) and velvetleaf (*Abutilon theophrasti*) (Dobbels and Kapusta 1993). In addition, nicosulfuron provides 80 to 100% control of seedling and rhizome johnsongrass (*Sorghum halepense*) (Camacho et al. 1991). Rimsulfuron provides more than 95% control of johnsongrass (Damalas and Eleftherohorinos 2001). In addition, nicosulfuron and rimsulfuron are packaged together and provide superior control of several grasses including barnyardgrass (*Echinochloa crus-galli*), green foxtail (*Setaria viridis*), yellow foxtail (*Setaria glauca*), witchgrass (*Panicum capillare*), and black-seeded proso millet

(*Panicum miliaceum*) (Swanton et al. 1996). The effectiveness of nicosulfuron and rimsulfuron for control of weedy grass species in corn led to nicosulfuron and rimsulfuron being applied to 18% of the corn hectares in the United States in 2005 (USDA 2006).

The widespread and regular use of sulfonylurea herbicides has, however, selected for weeds with resistant to ALS-inhibiting herbicides. The resistance mechanism is commonly associated with an insensitive ALS enzyme, although nontarget site resistance has been reported for rigid ryegrass (*Lolium rigidum*) (Christopher et al. 1994) and downy brome (*Bromus tectorum*) (Mallory-Smith et al. 1999). There are currently 74 dicotyledon and 21 monocotyledon weed species resistant to ALS-inhibiting herbicides (Heap 2006). Within the north-central region of the United States, 19 weed species very problematic in corn are reported to be resistant to ALS-inhibiting herbicides (Franssen et al. 2001; Heap 2006; Ohmes and Kendig 1999; White et al. 2002). Additional herbicides are frequently mixed with nicosulfuron and rimsulfuron for effective control of ALS-resistant weed species in corn.

One of the current tank-mix options for sulfonylurea herbicides is mesotrione. Mesotrione is a selective, systemic soil- and foliar-applied herbicide that controls annual broadleaf and certain grass weeds in corn. The herbicide is a member of the triketone family and functions through the inhibition of the enzyme *p*-hydroxyphenylpyruvate dioxygenase (HPPD, EC 1.13.11.27), which assists in the conversion of tyrosine to plastoquinone and alpha-tocopherol (Mitchell et al. 2001; Norris et al. 1998). The inhibition of HPPD results in reduced carotenoid biosynthesis and bleaching of pigments in susceptible species. Mesotrione readily translocates throughout susceptible plants, and induces tissue necrosis within 3 to 5 days (Vencil 2002). There are currently no published reports of weeds with resistance to mesotrione, which makes mesotrione a logical choice as a tank-mix partner with nicosulfuron and rimsulfuron.

Recent research, however, has reported that mixing mesotrione with sulfonylurea herbicides can decrease efficacy of sulfonylurea herbicides on green foxtail, yellow foxtail, and shattercane (*Sorghum bicolor*). The addition of atrazine to a tank mix of mesotrione and sulfonylurea herbicide or an increased mesotrione rate further decreases herbicide efficacy of sulfonylurea herbicides on shattercane and foxtail species (Schuster et al. 2004). The objectives of this research were to determine if absorption, translocation, or metabolism was the basis for the reduction in sulfonylurea herbicidal efficacy on green foxtail and yellow foxtail, when mixed with mesotrione or mesotrione + atrazine.

MATERIALS AND METHODS

Plant Materials

Green foxtail and yellow foxtail seeds were planted in separate 15-cm diameter containers filled with Morrill loam soil (fine-loamy, mixed, mesic Typic Argiudolls), with a pH of 6.4 and 2.1% OM. Plants were grown under greenhouse conditions of 26/24 ± 3 C day/night temperatures and 16 h photoperiod, with supplemental light intensity of 84 µmol m^{-2} s^{-1} photosynthetic photon flux (PPF). Commercial fertilizer[1] solution containing 0.40 mg L^{-1} nitrogen, 0.34 mg L^{-1} phosphorus, and 0.33 mg L^{-1} potassium was applied to supply nutrients as needed by the plants. After emergence, green and yellow foxtail seedlings were thinned to four plants per container.

Foliar Absorption and Translocation

Green foxtail and yellow foxtail were treated at the 4-leaf growth stage with ten 1-µl droplets of ^{14}C-nicosulfuron ([pyrimidine-2-^{14}C]-nicosulfuron, specific activity 2,300 MBq g^{-1})

or ^{14}C-rimsulfuron ([pyrimidine-2-^{14}C]-rimsulfuron, specific activity 1,302 MBq g^{-1}), applied uniformly across the adaxial surface of the third-oldest leaf of each plant. A single 1-µl droplet contained 61 Bq of ^{14}C-nicosulfuron or ^{14}C-rimsulfuron. Unlabeled nicosulfuron and rimsulfuron were added to the radioactive solutions to obtain 35 and 18 g ha^{-1}, respectively, in a carrier volume of 187 L ha^{-1}. These solutions of ^{14}C-labeled and unlabeled nicosulfuron or rimsulfuron were also applied with mesotrione at concentration equal to 105 g ha^{-1} or with mesotrione + atrazine at concentration equal to 105 and 757 g ha^{-1} dissolved in 187 L ha^{-1}. Crop oil concentrate[2] (COC) was added to all treatments at 0.5% vol vol^{-1} to enhance droplet-to-leaf surface contact.

Plants were harvested at 1, 3, and 7 days after treatment (DAT) and separated into treated leaf, treated tiller, other tillers, and roots. Treated leaves were washed in 15 ml of a 75% methanol solution to remove any unabsorbed herbicide. Radioactivity in the leaf rinsate was measured by using liquid scintillation spectrometry (LSS).[3] Plant sections were air-dried at 26 C for 48 h and then oxidized with a biological oxidizer.[4] Radioactivity recovered for each plant part was measured by using LSS. Herbicide absorption was calculated by dividing the radioactivity recovered in the entire plant by the total radioactivity applied to the plant. Herbicide translocation was calculated by dividing the radioactivity recovered in each plant part by the total radioactivity absorbed in the plant.

Herbicide Metabolism

To obtain enough plant material for this experiment, the 3 oldest leaves of green foxtail and yellow foxtail at the 4-leaf growth stage were treated with ^{14}C-nicosulfuron or rimsulfuron. A total of ten 1-µl droplets, containing 2130 or 2430 Bq of ^{14}C-nicosulfuron or ^{14}C-rimsulfuron, respectively, were applied to the adaxial surface of the 3 largest leaves on each plant in a container. Unlabeled herbicides were mixed with ^{14}C-nicosulfuron and rimsulfuron to reach the desired application rate as described in the foliar absorption and translocation study. In addition, solutions of ^{14}C-labled and unlabeled nicosulfuron or rimsulfuron were mixed with mesotrione (105 g ha^{-1}) or with mesotrione + atrazine (105 and 757 g ha^{-1}) and applied to green and yellow foxtail. Herbicide treatments included COC, as previously described.

Plants were harvested at 3 and 7 DAT. Leaves were rinsed twice in 75% methanol to remove any unabsorbed herbicides. Plants were then frozen in liquid nitrogen and ground to a fine powder with a mortar and pestle. Subsamples of the plants were weighed and oxidized, and captured $^{14}CO_2$ was measured by using LSS to determine the amount of radioactivity in the plant tissue. Samples were stored at -80 C until radioactivity was extracted.

Nicosulfuron and rimsulfuron were extracted according to the following procedure. Frozen plant tissue was homogenized with 15 ml of 75% methanol (by volume) and shaken for 1 h. Samples were then filtered with Whatman 4 filter paper[5], and the supernatant was saved. The remaining plant tissue was resuspended in 5 mL of 90% methanol and shaken for an additional 45 min. Samples were filtered, and the supernatant was added to the first supernatant. To determine the amount of radioactivity not extracted into the supernatant, the remaining plant residue and filter paper were oxidized, and radioactivity was measured. Supernatant was then evaporated to 0.5 ml in a centrivap[6] at 35 C. Solutions were then filtered with 0.2-µm filter[7] and stored at -20 C until use.

Extracts were injected into a Beckman high-performance liquid chromatograph[8] using a Zorbax ODS endcapped Sb-C18 column[9] (4.6 X 250 mm), operated at 25 C with a solvent system of 1% acetic acid in water and methanol at a flow rate of 1.5 ml min^{-1}. The elution profile was as follows: step 1, 5 to 20% methanol linear gradient for 10 min; step 2, 20 to 80%

methanol linear gradient for 10 min; step 3, 80 to 100% methanol linear gradient for 5 min; and step 4, 100 to 5% methanol linear gradient for 10 min. Radioactivity was measured with an EG&G Berthold scintillation spectroscope.[10] Corresponding elution times for metabolites were recorded. Nicosulfuron and rimsulfuron standards were included to determine when herbicide parent compound eluted from the column.

Experimental Design and Data Analyses

The foliar absorption and translocation and metabolism studies were randomized complete-block designs. Treatments were blocked by harvest time. Foliar absorption and translocation treatments were replicated six times, and the experiment was conducted three times. In the metabolism study, the treatments were replicated four times, and the experiment was repeated. Data were analyzed in both studies by using analysis of variance, and means were separated by using LSD at $P = 0.05$.

RESULTS AND DISCUSSION

Foliar Absorption

Nicosulfuron absorption increased over time. Nicosulfuron applied alone on green foxtail and yellow foxtail was absorbed 20 and 11%, respectively, at 1 DAT (Table 4.1). Absorption of the herbicide doubled in both species at 3 DAT, and nicosulfuron absorption was greater than 60% in green and yellow foxtail by 7 DAT. Mixing mesotrione and nicosulfuron resulted in a similar percentage of the nicosulfuron being absorbed 1 and 3 DAT; by 7 DAT, however, significantly less of the herbicide was absorbed. The addition of atrazine to the mesotrione and nicosulfuron mix resulted in further reduction in nicosulfuron absorption. At 3

DAT, nicosulfuron absorption was decreased by 21 and 10% in green foxtail and yellow foxtail, respectively, compared with absorption of nicosulfuron applied alone. Green foxtail and yellow foxtail absorption of nicosulfuron was 40 and 24% less, respectively, when nicosulfuron was applied in combination with mesotrione + atrazine at 7 DAT, compared with absorption when nicosulfuron was applied alone. This corresponds with previous research that indicated that control of green and yellow foxtail was less than 66% when nicosulfuron was mixed with mesotrione, as compared to greater than 80% control of the weed species when the sulfonylurea herbicide was applied alone (Schuster et al., unpublished data).

Green foxtail and yellow foxtail absorption of rimsulfuron were similar when rimsulfuron was applied alone (Table 4.1). Mixing mesotrione and rimsulfuron did not reduce the absorption of rimsulfuron in green foxtail at any of the harvest dates. Yellow foxtail absorption of rimsulfuron at 7 DAT was 11% lower when rimsulfuron was mixed with mesotrione, compared with absorption of rimsulfuron applied alone. Mesotrione + atrazine and rimsulfuron mixes resulted in significantly less rimsulfuron being absorbed into green foxtail and yellow foxtail than when rimsulfuron was applied alone. Application of rimsulfuron in combination with mesotrione and atrazine resulted in 6, 13, and 20% less absorption in green foxtail at 1, 3, and 7 DAT, respectively, compared with application of rimsulfuron alone. Yellow foxtail absorbed 61 and 41% of rimsulfuron when rimsulfuron was applied alone and when it was mixed with mesotrione + atrazine, respectively, at 7 DAT.

Herbicide Translocation

Nicosulfuron movement within green foxtail and yellow foxtail was determined by measuring ^{14}C translocation out of the treated leaf (Table 4.2). The translocation of nicosulfuron out of the treated leaf increased over time, but less than 40% of the absorbed nicosulfuron moved out of the treated leaf by 7 DAT. Mixing mesotrione with nicosulfuron reduced the translocation of nicosulfuron out of the treated leaf in green foxtail, with only 26% of the absorbed herbicide being translocated out of the treated leaf at 7 DAT. Similar reductions in nicosulfuron translocation out of the treated leaf in green foxtail were recorded when nicosulfuron was tank mixed with mesotrione + atrazine.

Translocation of nicosulfuron out of the treated leaf in yellow foxtail was less than translocation out of the treated leaf in green foxtail (Table 4.2). For example, an application of nicosulfuron alone on green foxtail and yellow foxtail resulted in 63 and 72% of the herbicide remaining in the treated leaf at 7 DAT, respectively. Nicosulfuron translocation in yellow foxtail was similar when nicosulfuron was applied alone or was applied in combination with mesotrione or mesotrione + atrazine. At 7 DAT, greater than 70% of the absorbed nicosulfuron was still present in the treated leaf of yellow foxtail after treatments of nicosulfuron alone or nicosulfuron tank mixed with mesotrione or mesotrione + atrazine.

Rimsulfuron translocation out of the treated leaf in green foxtail increased over time, regardless of treatment (Table 4.3). Green foxtail translocation of rimsulfuron was similar between applications of rimsulfuron alone and application of a mix of mesotrione and rimsulfuron. Mesotrione + atrazine and rimsulfuron, however, resulted in a greater percentage of the absorbed rimsulfuron remaining in the treated leaf, compared with rimsulfuron alone or rimsulfuron with mesotrione. Rimsulfuron translocation out of the treated leaf in green foxtail was reduced by 11% when rimsulfuron was tank mixed with mesotrione + atrazine, compared with translocation when rimsulfuron was applied alone.

Translocation of rimsulfuron out of the treated leaf was significantly less in yellow foxtail than in green foxtail at 7 DAT, regardless of treatment (Table 4.3). Mixing mesotrione or mesotrione + atrazine with rimsulfuron did not change the percentage of rimsulfuron being translocated out of the treated leaf at 7 DAT. The treated leaf of yellow foxtail retained 76, 78, and 83% of applied rimsulfuron when rimsulfuron was applied alone, in combination with mesotrione, or with mesotrione + atrazine, respectively. The similarity of rimsulfuron translocation between treatments of rimsulfuron applied alone, rimsulfuron with mesotrione, and rimsulfuron mixed with mesotrione + atrazine corresponds to the reduced antagonistic effect in green foxtail and yellow foxtail, compared with nicosulfuron treatments applied to the foxtail species, documented in previous research (Schuster et al. 2004).

Herbicide Metabolism

Metabolism of nicosulfuron and rimsulfuron occurred in green foxtail and yellow foxtail at 3 and 7 DAT (Table 4.4 & 4.5). Two distinct metabolites of ^{14}C-nicosulfuron were separated from the parent herbicide in green foxtail and yellow foxtail (Table 4.4). The nicosulfuron metabolites eluted at 9 and 12 minutes during the elution profile. The percentages of the nicosulfuron parent compound that remained in green foxtail at 3 and 7 DAT were 63 and 15%, respectively, when nicosulfuron was applied alone. Significantly less of the nicosulfuron parent compound remained at 3 DAT when nicosulfuron was applied to yellow foxtail, compared with green foxtail, but yellow foxtail metabolism of nicosulfuron was similar to that of green foxtail at 7 DAT. Previous researchers have identified herbicide metabolism as the primary basis for differential selectivity of nicosulfuron (Burton et al. 1992; Diehl et al. 1993; Green and Ulrich 1993). Species tolerant to an herbicide are able to metabolize it more rapidly and extensively than sensitive species; perhaps this explains yellow foxtail's initial decreased injury to nicosulfuron, compared with green foxtail. In both green foxtail and yellow foxtail, metabolism of nicosulfuron was similar between treatments of nicosulfuron applied alone and combinations of nicosulfuron mixed with mesotrione or mesotrione + atrazine.

Rimsulfuron parent compound and metabolite eluted at 19 and 13 min, respectively, during the elution profile (Table 4.5). Metabolism of rimsulfuron was similar between green foxtail and yellow foxtail at 3 DAT, with 80 and 78% of the rimsulfuron parent compound remaining in green foxtail and yellow foxtail, respectively, at 3 DAT, when rimsulfuron was applied alone. At 7 DAT, 48 and 67% of the rimsulfuron parent compound remained unaltered in green foxtail and yellow foxtail, respectively, when rimsulfuron was applied alone. The metabolism of rimsulfuron was similar between treatments of rimsulfuron applied alone and rimsulfuron mixed with mesotrione or mesotrione + atrazine.

CONCLUSIONS

Previous research has demonstrated that when mesotrione is mixed with a sulfonylurea herbicide, the herbicidal efficacy of the sulfonylurea herbicide on foxtail species is significantly reduced (Schuster et al. 2004). Adding atrazine to the tank mix results in a more pronounced decrease in control of weedy grass species. This research showed that the reduction in efficacy when nicosulfuron is applied in combination with mesotrione or mesotrione + atrazine is due to decreased absorption and translocation of nicosulfuron in green foxtail and decreased absorption in yellow foxtail. Mixing mesotrione with rimsulfuron did not result in reduced absorption or translocation of rimsulfuron in green foxtail; in yellow foxtail, however, absorption was decreased by 11% at 7 DAT. Mixes of mesotrione + atrazine and rimsulfuron resulted in significant decreases in absorption in both green foxtail and yellow foxtail. The reduction in the absorption of sulfonylurea herbicides when mixed with mesotrione + atrazine is possibly due to the destruction of epidermal cells at the point of contact (Thompson and Slife 1969). For example, once atrazine is absorbed by foliage, it is poorly translocated into the plant and acts primarily by indirectly enhancing lipid peroxidation and causing cell membrane disruption (Damalas and Eleftherohorinos et al. 2001). This results in rapid cell death at the point of contact, and sulfonylurea herbicides can become tightly adsorbed to dead tissue. Translocation of sulfonylurea herbicides in green and yellow foxtail is an active process, but lower concentrations of sulfonylurea herbicides in plant tissue result in decreased translocation from the point of contact to meristematic regions. Nicosulfuron and rimsulfuron metabolism in green and yellow foxtail is seemingly unaffected by mixing either one of them with mesotrione or with mesotrione + atrazine.

SOURCES OF MATERIALS

[1] Miracle-Gro Plant Food, Scotts Miracle-Gro Products Inc., P.O. Box 606, Marysville, OH 43040.

[2] Prime Oil, Terra International Inc., P.O. Box 6000, Sioux City, IA 53102-6000.

[3] Tricarb 2100TR Liquid Scintillation Analyzer, Packard Instrument Co., 800 Research Parkway, Meriden, CT 06450.

[4] R. J. Harvey Biological Oxidizer, Model OX-600, R. J. Harvey Instrument Co., 123 Patterson Street, Hillsdale, NJ 07642.

[5] Whatman International Ltd., Springfield Mill, James Whatman Way, Maidstone, Kent ME14 2LE, United Kingson.

[6] Centrivap, Labconco, 8811 Prospect, Kansas City, MO 64132.

[7] Filter paper, Osmonics Inc., 5951 Clearwater Drive, Monnetonka, MN 55343.

[8] Beckman high-performance liquid chromatograph, Beckman Coulter Inc., Life Science Research Division, 4300 N. Harbor Boulevard, P.O. Box 3100, Fullerton, CA 92834-3100.

[9] Zorbax ODS endcapped Sb-C18 column, Agilent Technologies, Chemical Analysis Group, 2850 Centerville Road, Wilmington, DE 19808.

[10] Scintillation spectroscope, EG&G Berthold, Postfach 100163, Bad Wilbad D-75312, Germany.

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Table 4.1. Nicosulfuron and rimsulfuron absorption in green foxtail and yellow foxtail when applied alone or in combination with mesotrione or mesotrione + atrazine 1, 3, and 7 DAT.[ab]

	Green foxtail			Yellow foxtail		
Herbicide	1 DAT	3 DAT	7 DAT	1 DAT	3 DAT	7 DAT
	% absorbed					
Nicosulfuron	20 ± 2	43 ± 2	65 ± 3	22 ± 2	43 ± 3	61 ± 5
Mesotrione + nicosulfuron	19 ± 2	40 ± 3	50 ± 4	20 ± 2	37 ± 4	48 ± 5
Mesotrione + atrazine + nicosulfuron	13 ± 2	22 ± 4	25 ± 5	18 ± 2	33 ± 4	37 ± 5
Rimsulfuron	21 ± 3	41 ± 3	65 ± 3	24 ± 3	44 ± 4	61 ± 6
Mesotrione + rimsulfuron	20 ± 2	35 ± 3	62 ± 3	22 ± 2	42 ± 3	50 ± 4
Mesotrione + atrazine + rimsulfuron	15 ± 2	18 ± 1	45 ± 2	17 ± 1	35 ± 3	41 ± 3

[a]Table values are means ± standard error.
[b]Abbreviation: DAT, days after treatment.

Table 4.2. Nicosulfuron translocation in green foxtail and yellow foxtail when applied alone or in combination with mesotrione or mesotrione + atrazine 1, 3, and 7 DAT.[ab]

		Green foxtail			Yellow foxtail		
Herbicide	Plant part	1 DAT	3 DAT	7 DAT	1 DAT	3 DAT	7 DAT
		% translocated					
Nicosulfuron	Root	3 ± 1	6 ± 1	9 ± 1	1 ± 2	4 ± 1	8 ± 1
	Treated tiller	13 ± 3	20 ± 2	28 ± 2	12 ± 2	17 ± 4	20 ± 4
	Other tillers	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Mesotrione + nicosulfuron	Root	4 ± 1	3 ± 1	6 ± 2	2 ± 2	3 ± 1	6 ± 1
	Treated tiller	10 ± 3	11 ± 2	19 ± 2	12 ± 1	19 ± 3	16 ± 4
	Other tillers	0 ± 0	1 ± 1	1 ± 1	0 ± 0	0 ± 0	0 ± 0
Mesotrione + atrazine + nicosulfuron	Root	3 ± 1	7 ± 2	9 ± 2	1 ± 1	3 ± 1	5 ± 1
	Treated tiller	7 ± 2	11 ± 2	19 ± 3	14 ± 1	15 ± 2	15 ± 3
	Other tillers	0 ± 0	1 ± 1	1 ± 1	0 ± 0	1 ± 1	1 ± 1

[a]Table values are means ± standard error.
[b]Abbreviation: DAT, days after treatment.

Table 4.3. Rimsulfuron translocation in green foxtail and yellow foxtail when applied alone or in combination with mesotrione or mesotrione + atrazine 1, 3, and 7 DAT.[ab]

		Green foxtail			Yellow foxtail		
Herbicide	Plant part	1 DAT	3 DAT	7 DAT	1 DAT	3 DAT	7 DAT
		% translocated					
Rimsulfuron alone	Root	4 ± 1	6 ± 1	10 ± 1	2 ± 1	4 ± 1	6 ± 1
	Treated tiller	16 ± 3	23 ± 2	30 ± 3	14 ± 2	18 ± 4	17 ± 3
	Other tillers	0 ± 0	0 ± 0	1 ± 1	0 ± 0	0 ± 0	1 ± 1
Mesotrione + rimsulfuron	Root	3 ± 1	4 ± 2	8 ± 1	3 ± 1	4 ± 1	4 ± 1
	Treated tiller	11 ± 3	20 ± 2	32 ± 3	13 ± 3	16 ± 4	16 ± 2
	Other tillers	0 ± 0	1 ± 1	0 ± 0	0 ± 0	1 ± 1	2 ± 1
Mesotrione + atrazine + rimsulfuron	Root	2 ± 1	6 ± 2	5 ± 1	3 ± 1	4 ± 1	2 ± 1
	Treated tiller	7 ± 4	10 ± 2	24 ± 3	12 ± 3	15 ± 5	14 ± 3
	Other tillers	0 ± 0	1 ± 1	1 ± 1	0 ± 0	1 ± 1	1 ± 1

[a]Table values are means ± standard error.
[b]Abbreviation: DAT, days after treatment.

Table 4.4. Nicosulfuron and metabolites at 3 and 7 DAT when applied alone or in combination with mesotrione or mesotrione + atrazine in green foxtail and yellow foxtail.[ab]

			Green foxtail		Yellow foxtail	
Treatment	Compound	Retention time	3 DAT	7 DAT	3 DAT	7 DAT
		min	% of radioactivity			
Nicosulfuron	Metabolite 1	9	10 ± 5	24 ± 5	30 ± 6	33 ± 5
	Metabolite 2	12	27± 2	61 ± 5	48 ± 5	53 ± 4
	Parent	18	63 ± 4	15 ± 4	22 ± 3	14 ± 3
Mesotrione + nicosulfuron	Metabolite 1	9	9 ± 5	24 ± 7	28 ± 5	30 ± 3
	Metabolite 2	12	26 ± 3	61 ± 7	49 ± 4	56 ± 7
	Parent	18	65 ± 4	15 ± 3	23 ± 3	14 ± 5
Mesotrione + atrazine + nicosulfuron	Metabolite 1	9	11 ± 6	27 ± 3	34 ± 9	32 ± 3
	Metabolite 2	12	26 ± 4	58 ± 3	48 ± 5	54 ± 3
	Parent	18	63 ± 5	15 ± 3	18 ± 4	14 ± 3

[a]Table values are means ± standard error.
[b]Abbreviation: DAT, days after treatment.

Table 4.5. Rimsulfuron and metabolite at 3 and 7 DAT when applied alone or in combination with mesotrione or mesotrione + atrazine in green foxtail and yellow foxtail.[ab]

			Green foxtail		Yellow foxtail	
Treatment	Compound	Retention time	3 DAT	7 DAT	3 DAT	7 DAT
		min	% of radioactivity			
Rimsulfuron	Metabolite 1	13	20 ± 5	52 ± 6	22 ± 3	33 ± 4
	Parent	19	80 ± 5	48 ± 6	78 ± 3	67 ± 6
Mesotrione + rimsulfuron	Metabolite 1	13	17 ± 5	56 ± 5	19 ± 4	31 ± 3
	Parent	19	83 ± 5	44 ± 5	81 ± 5	69 ± 3
Mesotrione + atrazine + rimsulfuron	Metabolite 1	13	19 ± 5	55 ± 3	18 ± 4	32 ± 3
	Parent	19	81 ± 5	45 ± 3	82 ± 3	68 ± 4

[a]Table values are means ± standard error.
[b]Abbreviation: DAT, days after treatment.