# A Laboratory Exercise for Teaching Critical Period for Weed Control Concepts 1

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# A Laboratory Exercise for Teaching Critical Period for Weed Control Concepts[1]

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**Abstract:** Crop–weed interactions is an important topic for introductory weed science courses. The effect of the timing of weed emergence and the duration of weed competition on crop yield are two topics usually covered when discussing competition. Students generally gain a better knowledge of these concepts through observation in addition to discussion of the underlying concepts. An additive removal and plant-back experiment was used, in the undergraduate weed science laboratory at Iowa State University, to demonstrate critical period for weed control concepts for cultivated radish. In one series of treatments, weeds were sown at the time of radish planting and removed at 2, 3, and 4 wk after planting. In another series, weeds were sown at 1, 2, and 4 wk after radish planting and allowed to grow in the flats until completion of the experiment. Two controls, one weed free and one unweeded, were also included. The results from four semesters suggested that the critical period for weed control began immediately after planting and lasted 3 wk. The timing and duration of the critical period was consistent across the four semesters evaluated. This activity was successful in demonstrating the critical period for weed control in radish.

**Nomenclature:** Radish, *Raphanus sativus* L.

**Additional index words:** Competition, education, weed ecology, weed-free period.

## INTRODUCTION

Competition between weeds and crops is one of the several ecological topics that comprise about one-half of the course material in the undergraduate weed science course taught to juniors and seniors at Iowa State University. According to Aldrich and Kremer (1997), competition between weeds and crops occurs when some factor, such as water, nutrients, or sunlight, is insufficient to meet the needs of both the weed and the desired plant. Competitiveness is the relative ability of a plant to obtain a specific resource when in competition with another plant.

The timing of weed emergence and duration of weed competition have a prominent effect on crop yields. Research studies have demonstrated that just a few days of early growth by the crop relative to weeds can greatly shift the competitive balance in favor of the crop over the weeds (Mohler 2001). The crop receives a relative advantage that often allows it to shade weeds at the time the plant canopies of the individual crop plants meet, which compounds size differences even further. Field research has also established that, in many instances, weeds do not compete much with crops if they are allowed to grow early in the season but are later removed (Zimdahl 1988). Water and nutrients are often in sufficient supply early in the season to support both the crop and weed seedlings and light competition does not occur until the weed canopy shades the crop. Therefore, little crop yield loss occurs if weeds are removed before light competition occurs and there is sufficient water and nutrient supply during the rest of the growing season.

Because there are times early and late in the crop growth period in which weeds do not interfere with crop yields, it is reasonable to expect that there is an interval in the life of the crop when it must be kept weed free to prevent yield loss. This period, often called the ‘‘critical period for weed control’’ or ‘‘critical weed-free period’’, has been established for many crops (Mohler 2001; Zimdahl 1980, 1988). The critical period for weed control is a useful measure because it gives an indication of when to exclude weeds and provides the manager with a conceptual basis for applying weed management techniques. Studying this period also allows for assessment of whether present methods of weed control are a function of biological necessity or merely a function of their availability and ease of use (Van Acker et al. 1993a).

Studies used to determine the critical period for weed control contain two series of treatments (Zimdahl 1980). In the first series, the crop is kept weed free for increasing intervals of time after seeding or emergence. After this period, weeds are allowed to grow for the rest of

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the crop season. In the second series, weeds are allowed to grow for increasing intervals after crop seeding or emergence followed by a weed-free period until the end of the growing season. This approach is sometimes called an additive removal and plant-back study (Miller and Hopen 1991; Monks and Schultheis 1998).

The following experiment was used to demonstrate weed interference with crops and to illustrate critical period for weed control concepts in an undergraduate weed science laboratory. Radish was selected as the crop in these studies because it produced a harvestable yield in a relatively short time period, was not very competitive so the effects of weeds were easily measured, and the fleshy root and shoot of radish provided an easily harvested and measured product. High densities of large-seeded, summer-annual, grass weeds were used because they quickly provided intense competition with the radish. Our objectives for this paper were to describe the experiment and an associated scientific writing assignment, evaluate the consistency of results across semesters, and assess student perceptions of the experiment and scientific writing activity.

## MATERIALS AND METHODS

**Plant Culture.** Students were organized into groups of four to plant, tend, and harvest the experiment. It was planted in four semesters with seeding dates of January 19, 2000, August 29, 2000, January 16, 2001, and January 22, 2002.

Galvanized metal flats with dimensions of 31 cm by 21 cm by 6 cm and 3.8 L capacity were filled to within 1 cm of the rim with Sunshine SB300 Universal Professional Growing Mix.[3] A weed seed mixture was created by thoroughly mixing approximately equal volumes of shattercane [*Sorghum bicolor* (L.) Moenchr], domesticated proso millet (*Panicum miliaceum* L.), and woolly cupgrass [*Eriochloa villosa* (Thunb.) Kunth] seed. The shattercane and woolly cupgrass seed were collected from fields near Ames, IA, in 1998 and the wild-proso millet seed were purchased[4] in 1998. All seed were stored at 4 C until used for the experiment.

Two lengthwise rows were created in each flat using a pot stake as a furrowing tool. Eight radish seeds were placed equidistantly in each row at a depth of 1 cm, covered with potting medium, and tamped lightly. Eight trays were seeded per student group. Emerged radish plants were thinned to five per row (about 1 plant/4 cm) at 1 wk after planting by clipping at the base of the plant near the soil surface.

An additive removal and plant-back approach was used to determine the critical weed control period for the radish. The eight treatments used for the experiment were: two controls, one weed-free, and one unweeded for the duration of the experiment; weeds seeded at the time of radish planting and removed at 2, 3, and 4 wk after planting (additive removal); and weeds seeded at 1, 2, and 4 wk after radish planting and left in the flats until completion of the experiment (additive plant-back). Five grams of weed seed were spaced evenly on the surface of the flat and covered with 0.5 cm of potting medium. Weed seedlings were removed at appropriate times by clipping the weeds near the soil surface with scissors. Any weed regrowth was clipped each week to keep the treatments weed free for the remainder of the experiment.

The seeded flats were placed in the Agronomy Teaching Greenhouse, Iowa State University, for the duration of the growth period. The temperature regimen was 22–18 C (day–night). Water was provided by an overhead sprinkler system that operated for 2 min and 15 s every 1.5 h during daylight hours. High intensity sodium light was used to supplement natural sunlight and maintain a 15-h photoperiod. Five grams of 17–6–12 controlled release fertilizer with micronutrients[5] were topdressed per flat 2 wk after planting the radish.

**Data Collection, Organization, and Presentation.** Radish plants were harvested from all treatments at 6 wk after planting. The fleshy root and shoots of the radish plants were gently removed from the soil, washed, and patted dry with paper towels in three of the semesters. In spring 2001, only the radish roots were weighed. Fresh weight of the radish plants from each treatment was recorded. For course purposes, data from all student groups were combined each semester and graphed using computer spreadsheet software.

Students presented the data in a six-page scientific paper that followed formatting guidelines established by the American Society of Agronomy (ASA, CSSA, SSSA, 1998). The College of Agriculture at Iowa State University has formulated learner outcomes that address the knowledge and skills that students should possess on graduation. This experiment and the associated scientific paper assignment addressed several of these learner outcomes. Specifically, these activities were intended to foster the ability to (1) write clearly and persuasively, (2)

[3] Sunshine SB300 Universal Professional Growing Mix, Sun Gro Horticulture, Inc., Bellevue, WA 98008.

[4] Domesticated proso millet seed, Valley Seed Service, Fresno, CA 93791.

[5] Fertilizer with micronutrients, Scotts-Sierra Horticultural Products Company, Marysville, OH 43041.

*Table 1.* Questions used to stimulate student inquiry into the data collected from a plant competition experiment in the weed science course at Iowa State University. Students were required to answer these questions in a results and discussion section of a scientific paper.

1. When did yield decreases occur assuming that an acceptable yield level is 95% of that produced by the weed-free radish?
2. What was the effect on radish yield when weeds emerged with the crop and were allowed to grow for two, three, four, and six weeks?
3. What was the effect on radish yield when the radish plants were kept weed-free from planting until two, four, five, and six weeks after planting?
4. Is there a critical weed-free period demonstrated by a graph of the data?
5. When did application of weed control maximize radish yield?
6. Would you expect the same results if the radish and weeds were growing in the greenhouse in summer rather than winter (remember the species involved)?
7. Would you expect the same results with downy brome, wild oat, or field pennycress competing with the radish in the greenhouse during winter? (Remember that these species are well adapted for growth at cooler temperatures.)
8. How can the results of this experiment be applied to crop production and integrated weed management?

receive information effectively through reading, listening, and observation, and (3) summarize, analyze, and interpret simple research data.

Whereas the experiments were performed in groups, writing the scientific paper was an individual assignment. The students purchased a course packet at the beginning of each semester that contained very specific formatting requirements for the paper and a scientific article used as an illustrative example (Blackshaw 1993). Although the page requirements for this paper (six pages of double-spaced lines) were considerably less than most scientific manuscripts, the paper was expected to be of professional quality.

Because this was generally the first experience with scientific writing for most students in our course, we developed a 4-wk series of active-learning activities on writing scientific papers. Students began preparing the scientific paper 1 wk before the experiments were harvested. During the laboratory period for that week, students participated in a ‘‘read and explain pairs’’ activity (Johnson et al. 1998) in which they read the instructions for the scientific paper from the course packet. Students worked in pairs to summarize the guidelines for selecting a title, writing an introduction, describing materials and methods, and citing literature. The reading was divided into sections. After each section was read individually, students summarized the content to their partner. The partners agreed on a summary of the reading and these steps were repeated until the reading was completed. Students were held accountable at the end of the activity by being called on at random to introduce their partner and summarize a section of the reading.

Immediately after the read and explain pairs activity, students moved to our computer facility where they received instruction on using search engines and indexes to find scientific literature. During this activity, students were required to find two scientific literature sources for their paper. They were organized into their experimental groups where they formulated a literature-cited section for their papers using the sources collected by the group members. A grading rubric designed by the course instructors for the scientific paper assignment (Figure 1) and a list of technical specifications for the experiment were handed out at the conclusion of the laboratory period. Students were assigned to select a title and to draft the introduction and materials and methods sections by the next laboratory period.

The experiment was harvested in the following week's laboratory period. Before the harvest, a cooperative learning exercise was used for peer review of the title, introduction, and materials and methods of the scientific papers. The students were organized into pairs at random and used the grading rubric to critically assess each other's writing. The laboratory instructor used a set of overhead visuals to guide the students through the review process.

The week after the experiment's harvest was dedicated to presentation of the results and development of the results and discussion section of the scientific paper. A read and explain pairs activity was used to review sections of the course packet on communicating results, preparing tables and figures, and discussing important results and concepts. Students were randomly assigned a new partner for this activity. The experimental data for all groups in two course sections were given to students. As part of the laboratory session, students worked collaboratively with others in their experiment group, with guidance from the laboratory instructor, to create graphs of the data using a spreadsheet program. Students were given a list of questions to answer in their results and discussion section (Table 1) and a first draft of the entire scientific paper was assigned for the next week's laboratory period.

The final activity for the scientific paper assignment was a peer review of the results and discussion and literature cited sections 2 wk after the experiment's harvest. Students were paired with the same partner they had for the earlier peer review. The final draft of the paper was submitted to the laboratory instructor 3 wk

**Scientific Paper – Grade Report**

| | | | |
|---|---|---|---|
| **Name:** | | | |
| **Evaluator:** | | | |
| **Criteria** | | | **Points Earned** |
| **Proper outline** – *10 points total (0-2 points each)* | | | |
| Typed, double-spaced with one-inch margins. | | | |
| Not more than six typewritten pages. | | | |
| Contains all required sections and each section has a heading, centered and all-capitals. | | | |
| Appropriate title centered on first page with author's name two lines below. | | | |
| SI units used throughout the report. | | | |
| **Introduction** – *20 points total (0-5 points each)* | | | |
| *Beginning (0-1 points)* | *Developing (2-4 points)* | *Accomplished (5 points)* | |
| Does not identify the subject and define the problem being answered. | Identification of the subject and definition of the problem not clear. | Clearly identifies the subject and defines the problem being answered. | |
| Provides no accounting of previous inquiry in the area. | Provides some accounting of previous inquiry in the area. | Provides a advanced accounting of previous inquiry in the area | |
| Does not supply background for understanding and evaluating the results. | Supplies some background for allowing the reader to understand and evaluate the results of the present study without having to refer to previous publications. | Supplies sufficient background to allow the reader to understand and evaluate the results of the present study without having to refer to previous publications. | |
| Does not explain the general approach and objectives of the study. | Explanation of the general approach and objectives of the study could be clearer. | Clearly explains the general approach and objectives of the study. | |
| **Materials and Methods**– *12 points total (0-2 points each)* | | | |
| Written as prose (not as an outline) | | | |
| Methods described in sufficient detail that the experiment could be repeated. | | | |
| Includes names and locations of manufacturers of materials used. | | | |
| Plants identified by scientific name with appropriate taxonomic authority. | | | |
| Includes reference to source of methods. | | | |
| Explains how data were collected, assembled, and interpreted. | | | |

*Figure 1.* Grading rubric for the scientific paper assignment.

after the experiment was harvested. The papers were scored using the grading rubric handed out at the beginning of the assignment.

The experiment and scientific writing exercises were a part of the laboratory work for 10 wk. Planting in week 1 required 50 min and maintenance of the experiment in weeks 2 through 6 required 15 min per laboratory session. Fifty minutes of laboratory session 7 were necessary for harvest and data collection. One hour of laboratory sessions 6 through 10 were used for the scientific writing exercises.

**Statistical Analysis.** In this study, the experimental data from four semesters were analyzed using the general linear models procedure of SAS[6] to determine if measurable differences in growth occurred among treatments, semesters, and student groups. Because students enrolled

[6] General linear models procedure, SAS Institute, Cary, NC 27513.

| **Results and Discussion**– *40 points total (0-5 points each)* | | | |
|---|---|---|---|
| *Beginning (0-1 points)* | *Developing (2-4 points)* | *Accomplished (5 points)* | |
| Figures and tables inadequate, procedures outlined in handouts were not followed. | Figures and tables need improvement; some procedures in the handouts were followed | Figures and tables stand alone, complete and informative by themselves and follow procedures outlined in handouts. | |
| Figures and tables do not have captions or headings. | Figure captions and table headings do not succinctly and sufficiently describe figure and table contents. | Figures and tables have captions or headings that succinctly and sufficiently describe their contents. | |
| Most of the data presented in tables are duplicated in graphs | Some data presented in tables are duplicated in graphs and vice versa. | Data presented in tables are not duplicated in graphs and vice versa. | |
| The figures and tables are not referenced in text. | Only some of the figures or tables are referenced in text. | All figures and tables are referenced in text. | |
| Discussion does not relate results to the objectives of the study. | Discussion vaguely relates results to the objectives of the study. | Discussion clearly relates results to the objectives of the study. | |
| Discussion does not explain the principles and relationships illustrated by the results. | Discussion vaguely explains the principles and relationships illustrated by the results. | Discussion clearly explains the principles and relationships illustrated by the results. | |
| Discussion does not contain an accounting of how the results relate to previous findings. | Discussion contains a vague accounting of how the results relate to previous findings. | Discussion contains a clear accounting of how the results relate to previous findings. | |
| Discussion does not include conclusions supported by the evidence gathered. | Discussion includes conclusions, but they are not clearly supported by the evidence. | Discussion includes conclusions clearly supported by the evidence gathered. | |
| **Literature cited**– *6 points total (0-2 points each)* | | | |
| Literature is referenced in text using the name-year system. | | | |
| The reference list contains at least 6 information sources. | | | |
| Each reference in the Literature Cited section includes, in order, the authors, year of publication, full title of the articles, publication in which it appears, and volume and inclusive page numbers. | | | |
| **Group Participation and Evaluation**– *12 points total (0-4 points each)* | | | |
| *Inadequate (0-1 points)* | *Adequate (2-3 points)* | *Exemplary (4 points)* | |
| Did not participate in evaluation of other's work; did not take the evaluation role seriously | Evaluated other's work, but should have taken the evaluation role more seriously | Willingly participated in evaluation of other's work | |
| Evaluations were not done or poorly represented the quality of the work being critiqued | Evaluations were done, but did not represent the quality of the work being critiqued | Evaluations adequately represented the quality of the work being critiqued | |
| Evaluation was not constructive or helpful | A more thorough evaluation would have improved the work significantly | Evaluation provided positive feedback and significantly improved the quality of the work | |
| **Total Score (100 possible)** | | | |

*Figure 1.* Continued.

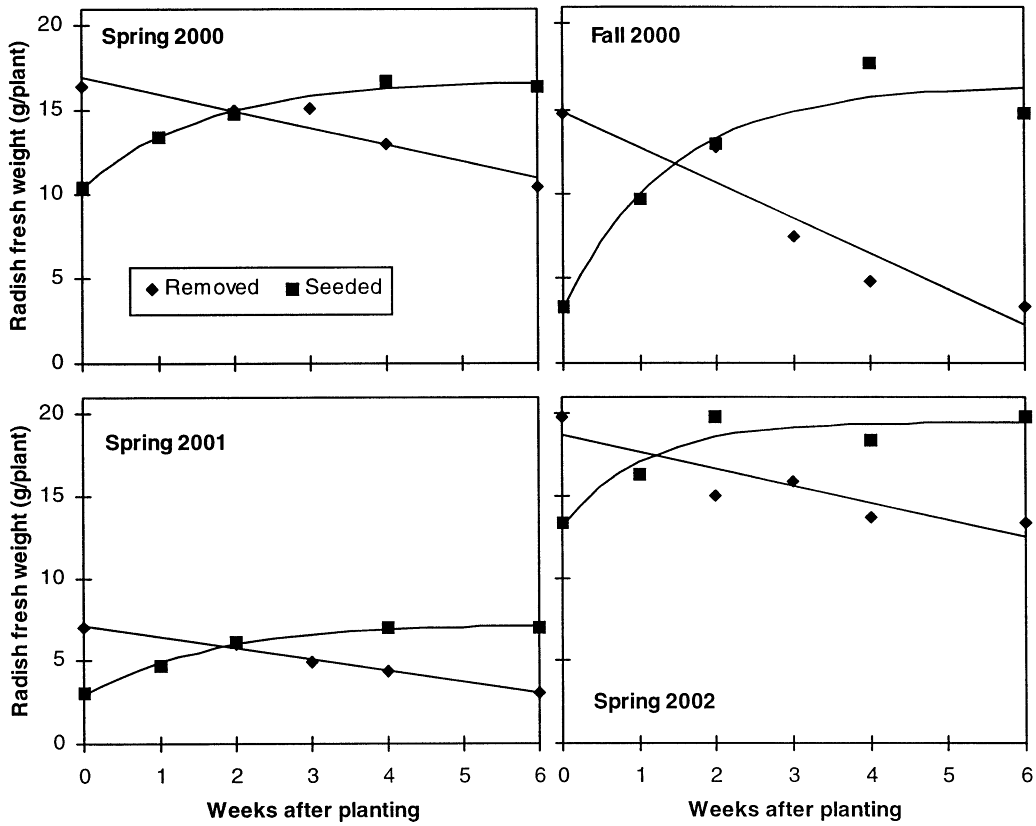


*Figure 2.* The relationship between competition from grass weeds and radish, fresh weight for four semesters of the undergraduate weed science course at Iowa State University. Both the radish shoot and root were weighed in fall 2000, spring 2000, and spring 2001. Only the radish roots were weighed in spring 2001. Equations for the predicted curves are presented in Table 2.

in the course changed each semester, groups were nested within semesters. The significance level for all statistical comparisons was $P \leq 0.05$. The experiment data were further evaluated using regression analysis. Equations were determined for the weeds removed data using a linear curve fitting function. The yield response curve to weeds seeded should follow a nonlinear hyperbola, which levels off at an asymptote. Therefore, the equation for Mitscherlich's Law of Diminishing Returns was used to fit lines to the weeds seeded data using Proc NLIN of SAS (Snedecor and Cochran 1989). The form of the equation used was

$$y = \mathrm{A} - \mathrm{B}\,(e^{-cx}) \qquad [1]$$

where $y$ = radish yield, A = maximum possible yield, B = the difference between the maximum possible yield and yield when weeds were seeded at radish planting, c = constant, and $x$ = week after planting. Student evaluation of this activity from one semester was presented as the mean and standard deviation of 18 responses. The correlation procedure of SAS was used to determine associations between student perceptions of the experiment and scientific writing assignment as valuable activities and other evaluation responses.

## RESULTS AND DISCUSSION

**Experimental Results.** Radish fresh weight varied by semesters, groups within semesters, and treatment (data not shown). The interaction between treatment and semester was also significant (data not shown). Average yield level was 14.3, 10.4, 5.4, and 16.5 g for spring 2000, fall 2000, spring 2001, and spring 2002, respectively. Overall radish yields for spring 2001 were lower than the other semesters because the radish shoots were removed from the plants and only the roots were weighed.

The results from all four semesters suggest that the critical period for weed control began immediately after planting of the radish (Figure 2). It should be noted, however, that space constraints kept us from including treatments in which weeds were removed during the first 2 wk of radish growth. Radish fresh weight, generally, followed a linear response to weed removal, with yield declining the longer the weeds remained in the crop.

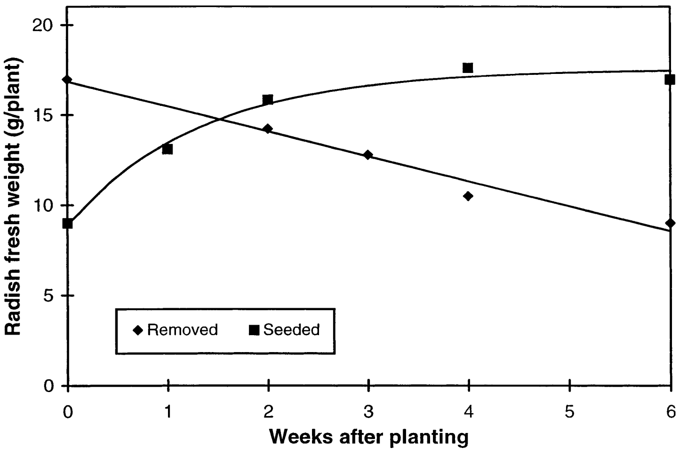


*Figure 3.* The relationship between competition from grass weeds and radish (fresh weight). Curves represent the combined data for the fall 2000, spring 2000, and spring 2002 semesters from the undergraduate weed science course at Iowa State University. Spring 2001 was not included in the combined data set because only the radish roots were harvested. Equations for the predicted curves are presented in Table 2.

*Table 2.* Regression equations and $R^2$ values for the response of radish fresh weight to competition from grass weeds from four semesters of the undergraduate weed science course at Iowa State University.

| Semester | Treatment[a] | Equation[b] | $R^2$ |
|---|---|---|---|
| Spring 2000 | Removed | $y = -1\ (x) + 16.98$ | 0.91 |
| | Seeded | $y = 16.8050 - 6.4224 \times e^{-0.6303(x)}$ | 0.99 |
| Fall 2000 | Removed | $y = -2.105\ (x) + 14.895$ | 0.90 |
| | Seeded | $y = 16.3814 - 13.2412 \times e^{-0.7222(x)}$ | 0.99 |
| Spring 2001 | Removed | $y = 0.6747\ (x) + 7.0872$ | 0.99 |
| | Seeded | $y = 7.2459 - 4.3048 \times e^{-0.6059(x)}$ | 0.99 |
| Spring 2002 | Removed | $y = -1.04\ (x) + 18.66$ | 0.80 |
| | Seeded | $y = 19.4862 - 6.3137 \times e^{-0.9562(x)}$ | 0.99 |
| Combined | Removed | $y = -1.3817\ (x) + 16.845$ | 0.98 |
| | Seeded | $y = 17.5510 - 8.6464 \times e^{-0.7434(x)}$ | 0.99 |

[a] Weeds were either seeded with the crop and removed at 2, 3 or 4 wk after planting or seeded at 1, 2, or 4 wk after planting and allowed to grow for the duration of the 6-wk growth period. An unweeded control and a weed-free control were used when determining both the removed and seeded equations.

[b] The radish weight response to removed weeds was fit to the linear equation $y = mx + b$ where $y$ is radish yield, $m$ is slope, x is wk after planting, and $b$ is the $y$-intercept. The response to seeded weeds was fit to $y = \mathrm{A} - \mathrm{B}(e^{-cx})$, where A is maximum possible yield, B is the difference between the maximum possible yield and yield when weeds were seeded at radish planting, and c is a constant.

Data combined for the three semesters in which both the radish shoots and roots were harvested (Figure 3; corresponding equations and $R^2$ values in Table 2) demonstrated that radish yield declined 1.4 g/plant for each week that weeds remained in competition with the crop. Radish fresh weight increased, as weed emergence was delayed. Yield curves for seeded weeds from each of the semesters and the combined data suggest that the third week after planting was the end of the critical period for weed control in radish.

When comparing the three semesters in which both the radish shoots and roots were weighed, the yield of the weed-free control was similar for spring and fall 2000 but was about 21% greater in spring 2002 (Figure 2). The reasons for this are unknown. The reduction in radish yield from competition was more pronounced in fall 2000 than in any of the spring semesters, suggesting that the time of year influenced the competitive interaction between the crop and weeds. The yield reduction from 6-wk of competition during fall 2000 was 78%. The yield reduction was 37, 33, and 56% for spring 2000, spring 2001, and spring 2002, respectively. The experiment was performed from the second to the eighth week of each semester. Early growth of the weeds and radish occurred under generally warmer temperatures (because air temperature was controlled by a heater and exchange with outside air, temperatures could exceed 22 C during warm days) and longer sunlight duration during the fall semester when compared with the spring semesters. Because radish is a cool-season crop and the weeds were warm-season species, the warmer fall temperatures may have favored the growth of the weeds at the expense of the crop.

The timing and duration of the critical period for weed control, which began at planting and lasted for 3 wk was quite constant across the four semesters of these radish experiments. This consistency is probably not typical of field situations with most crops. Field research studies suggest that critical period for weed control within a crop is influenced by season, soil conditions, weed species, weed density, location and management practices (Holloway and Shaw 1996; Kropff et al. 1992; Miller and Hopen, 1991; Mulugeta and Boerboom 2000; Stoller et al. 1987; Van Acker et al. 1993a, 1993b). Mechanistic simulation models of crop–weed competition in sugar beet (*Beta vulgaris* L.) and tomato (*Lycopersicon esculentum* Mill.) suggested that the greater the weed density, the shorter the period of time that the crop could tolerate early-season competition and the longer the period of time that the crop must be kept weed free to prevent yield losses (Weaver et al. 1992). These simulations also suggested that the length of time that a crop can tolerate early-season competition is related to the availability of soil moisture and essential nutrients. The stability of the critical period for weed control across semesters in the current student experiments most likely resulted from the use of consistently high weed densities, moisture levels, and nutrient additions.

**Student Assessment.** Student assessment of the experiment, scientific paper assignment, and active-learning exercises was done immediately after students handed in

*Table 3.* Student evaluation of the plant competition experiment and scientific paper assignment.[a,b]

| Statement | Mean | Standard deviation |
|---|---|---|
| This was a valuable activity. | 2.6 | 0.8 |
| I have an increased understanding of weed biology after completing this activity. | 2.5 | 1.0 |
| I have an increased understanding of weed management after completing this activity. | 2.4 | 1.2 |
| I can transfer the concepts learned in this activity to other situations. | 2.3 | 0.9 |
| This activity improved my critical thinking skills. | 2.7 | 1.2 |
| This activity improved my ability to write clearly. | 2.9 | 1.0 |
| This activity improved my ability to receive information effectively through reading. | 3.1 | 0.9 |
| This activity improved my ability to receive information effectively through observation. | 2.5 | 1.1 |
| This activity improved my ability to summarize simple research data. | 2.5 | 0.8 |
| This activity improved my ability to analyze simple research data. | 2.5 | 1.0 |
| This activity improved my ability to interpret graphical information. | 3.1 | 1.2 |
| Completion of this activity required effective time management. | 1.9 | 1.0 |
| Peer evaluation of my scientific paper improved my writing skills. | 2.7 | 1.2 |
| Peer evaluation of my scientific paper resulted in a better final product. | 2.6 | 1.2 |

[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 = 18.

the scientific paper in spring 2002. Fourteen statements (Table 3) were rated on a scale of 1 to 5, with 1 being strong agreement, 3 as neutral, and 5 as strong disagreement. Students were asked to identify their major as agronomy, horticulture, turf grass, agricultural business, agricultural studies, animal ecology, or other. There were no significant differences in responses from the students in varying majors.

The standard deviations for all questions were quite large relative to the means, indicating a wide range of responses among the students (Table 3). The ratings for all questions, except one, were not significantly different from neutral. Students agreed that completion of the activity required effective time management, which is a trait often cited by employers as being critically important, but generally lacking in recent college graduates. Interestingly, students were neutral as to whether the scientific writing assignment improved their ability to write clearly, which was one of the major goals of the assignment. It may be that students did not feel completely comfortable with scientific writing after completing only one assignment. Some students may have questioned the value of a scientific writing assignment to their career aspirations or were dissatisfied with the amount of work required to complete the paper.

Correlation coefficients were used to determine if there were relationships between students viewing the assignment as valuable and the other assessment questions (Table 4). This analysis indicated that students, who agreed that this was a valuable activity, thought the activity increased their understanding of weed management, improved their ability to interpret graphical information, and required effective time management. However, these students were not able to transfer the concepts learned in this activity to other situations and did not think that peer evaluation improved their paper.

**Instructor Perceptions.** This experiment was quite successful at demonstrating concepts related to the critical period for weed control. The timing and duration of the

*Table 4.* Correlations between student perception of the plant competition experiment and scientific paper assignment as a valuable activity (the first statement in Table 3) and other evaluation statements.

| Statement | Coefficient of correlation ($r$) | P > $r$ |
|---|---|---|
| I have an increased understanding of weed biology after completing this activity. | 0.41 | 0.08 |
| I have an increased understanding of weed management after completing this activity. | 0.61 | 0.01 |
| I can transfer the concepts learned in this activity to other situations. | 0.11 | 0.64 |
| This activity improved my critical thinking skills. | 0.43 | 0.07 |
| This activity improved my ability to write clearly. | 0.32 | 0.19 |
| This activity improved my ability to receive information effectively through reading. | 0.42 | 0.07 |
| This activity improved my ability to receive information effectively through observation. | 0.37 | 0.12 |
| This activity improved my ability to summarize simple research data. | 0.32 | 0.19 |
| This activity improved my ability to analyze simple research data. | 0.27 | 0.26 |
| This activity improved my ability to interpret graphical information. | 0.48 | 0.037 |
| Completion of this activity required effective time management. | 0.55 | 0.015 |
| Peer evaluation of my scientific paper improved my writing skills. | 0.16 | 0.51 |
| Peer evaluation of my scientific paper resulted in a better final product. | 0.23 | 0.35 |

critical period were consistent across the four semesters evaluated. Addition of a 1-wk removal timing and a 3-wk seeding date would allow for a more complete data set. The associated scientific writing assignment and active learning exercises allowed students to organize and present their data much the same way as a research scientist would. Students struggled at times with the complexity of the assignment and their unfamiliarity with scientific writing. Areas that need improvement are expanding students' ability to incorporate the results of previous research on the subject into their paper and transfer the concepts learned to other situations. Addition of the active learning activities and the grading rubric has greatly improved the quality of the scientific papers compared with previous papers.

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