FEATURE

An Undergraduate Laboratory Project for Greenhouse Management and Related Courses in Plant Sciences

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The Dept. of Horticulture at Virginia Tech, as do many others at other land-grant institutions, offers a course entitled Greenhouse Management (GM). It has a four-semester-credit lecture/laboratory format dealing primarily with greenhouse management principles. Until recently, horticulture majors were required to take GM as sophomores; a few juniors and seniors enrolled, as did an occasional nonhorticulture major.

Lecture material was originally structured to illustrate successful plant growth criteria in controlled conditions, in addition to discussing growth manipulation methods. It was necessary to design a laboratory whereby each student observed the immediate and long-term effects of greenhouse environment manipulation. Since emphasis was on individual student involvement, field trips were not arranged because less-motivated students generally fall into the background and become passive. Second, Blacksburg is located far from the centers of greenhouse commodity production and would require travel exceeding the usual laboratory time available. Therefore, the laboratory project described herein was developed in response to these situations and has been used and revised for more than 6 years. The course is team-taught, with one instructor teaching the laboratory, which comprises 25% of the student's final grade, and another full-time faculty member handling lectures. Laboratory and lecture are taken concurrently. Each student works independently and is required to purchase only two materials, to complete the term-long project—a clear plastic metric ruler and a computer diskette.

Physical set-up

A basic greenhouse floor plan is necessary for the project. The space shown in Fig. 1 easily accommodates an enrollment of 30 to 40 students, divided into two equal sections meeting on different days. The total space has four defined, linear areas. Area I creates a long-day regime using 60-W incandescent bulbs 1.2 m above the bench, spaced 1.2 m apart, and timed to be on from 10:00 PM to 2:00 AM. A light exclusion curtain is pulled between areas I and II at the end of each day to minimize stray light during the night interruption treatment; it is reopened at 8:00

AM. Photosynthesis is enhanced in Area II with one 400-W sodium vapor lamp mounted 1 m above each bench top. This light distribution density may neither be optimum nor commercially analogous, but, given the mixture of species used, significant results are achieved and the equipment fits within the tight budgets of an instructional program. The individual nature of this project is displayed in area III; each student puts plants here that have been mechanically or chemically treated. No two students in the same class section share the same treatment in area III if they

possess the same species. These treatments do not necessarily yield beneficial effects. This approach allows students to study responses to chemical and mechanical manipulation, including the undesirable effects of phytotoxicities and pollutants. Treatments that are easily applied, inexpensive, and noticeably effective are listed in Table 1. While aesthetically better results could be obtained by tailoring rates to individual species, simplicity is important while not compromising the chance of quantifiable responses. Students observe the effects of chemical growth

Fig. 1. Floor plan for plant manipulation project. Circles above area I represent 60-W incandescent bulbs; hexagons in area II represent 400-W HID high-pressure sodium lamps; and a curtain between areas I and II is drawn from 5:00 PM to 8:00 AM, represented by jagged line. Greenhouse measures 9 × 18.3 m (drawing not to scale).

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Table 1. Descriptions of previously used treatments and their modes of application for plants placed in area III.

Ancymidol (A-rest), 25 ppm, 20 ml solution/pot.
Cycocel (CCC), 2000 ppm, 20 ml solution/pot.
Daminozide (B-9), 2000 ppm, 20 ml solution/pot.
Dikegulac sodium (Atrinal), 250 ppm, foliar application [†] .
Ethylene (Florel), 1000 ppm, foliar application [†] .
Gibberellin (GA ₃ or GA ₄₊₇), 25 ppm, foliar application [†] .
Pinch apex, remove the smallest leaves including the stem tip.

[†]About 3 to 5 ml/plant is delivered via a hand-pumped spray bottle.

Table 2. Suggested data collected by students to illustrate growth responses to environmental, chemical, and/or mechanical manipulation.

Number of individual leaves/plant: Taken weekly, make sure students recognize simple vs. compound leaves; count only those on the main stem.
Plant width (cm): Taken weekly, ideally use main stem as center axis.
Plant height (cm): Taken weekly.
Number of individual branches/plant: Taken weekly, only from main stem. Define a branch as being at least 3 to 5 mm to avoid recording dormant buds.
Number of days from treatment to first flower: Students meet once per week so this is an estimate; however, species that show differences are usually very obvious.
Total number of flowers/plant at the end of the experiment: This count includes both dead and open flowers. Most species assigned here will leave evidence of floral senescence, making counting simple and reasonably accurate (e.g., fruits, persistent peduncles, calyces, or petals).
Differences in foliage color: Approached subjectively, several treatments cause obvious foliar chlorosis or dense greening. Students merely note appearance date and persistence.
Changes in leaf shape: As with foliar color changes, this is not quantified, but only recorded when seen and sketched for the report.

regulation on plants and are able to compare the relative potency of one chemical to another. Finally, controls are grown in area IV, where plants receive decreasing light intensity and shorter days as the season progresses from September through December.

Student responsibilities

On the first day of class, each student randomly selects a number-letter combination that refers to the flat of unnamed plants from which to choose (number), and the letter of the Combination specifies the particular area III treatment. The student also signs a master list at this time for the instructor's permanent records. Plant identity remains unknown until a custom-developed key is used to determine the family and genus. Since the key requires morphological information, students are advised to key-out their plants on several occasions before making a final judgment. Plant identification is worth only 10% of the project grade, but it has proven beneficial in at least two ways. Students work through a key, an important exercise for future plant identification, and, second, students become familiar with classic references such as *Bailey's Standard Cyclopedia of Horticulture* and *Flowering Plants of the World*, by V.H. Heywood. Hortus III has not been substituted for the former because Bailey has excellent line drawings to aid identification; and none of the chosen species are, in disputed families or genera.

The signed master list indicates the data each student must collect, and is species-dependent. Also included is a description of required weekly measurements and data that must be recorded only when initially observed. For example, most students record weekly height measurements, while others are required to take the date of first bloom and/or the number of open flowers at the

termination of the experiment. Measurements and observations that have successfully illustrated treatment responses in the past are listed in Table 2. Simplicity is the rule. Should any data become tedious by midsemester, e.g., counting leaves, students may request a reprieve only if substantiated with reasons supported by the previous weeks' data. In other words, mere complaints are not convincing, but showing the instructor that no area is eliciting a specific response is. Uniformity of data collection is essential. Data requirements as straightforward as plant height can be interpreted differently, because some will measure from soil level and others from the rim of the pot. Also, the highest point can be interpreted as the stem apex or the level defined by uppermost leaf expansion. Such decisions and options are discussed with each student rather than preselecting one method as best. The main point is that the same criteria be used throughout the study. Most students assess the effectiveness of the data collected at the end of the semester by informally comparing results with classmates.

Certain species perform exceptionally well, and others, as some students say, may be pretty weird. Aiming for unfamiliarity is intentional and necessitates the use of the identification key. From the instructor's view, the first few weeks are enjoyable as students try to guess the identity of their plants by sight. Responses of species used frequently in the past are summarized in Table 3. Although about 10 species are selected each year, I include one that has never been tested to determine its suitability for the future. A good "bank" of possibilities lets the instructor choose a slightly different species mix each year and sow them early enough for class use (Table 4).

Each student also records greenhouse tem-

perature and light intensity weekly. The latter is done at plant level in each of the linear areas with a hand-held foot-candle meter. Students are informed that this instrument provides only an estimate of light useful for plant growth. Most important, the value of using high-intensity discharge (HID) lamps is immediately evident on cloudy days, since area II has the highest light intensity readings. The potentially detrimental effects of shading can also be documented. Data collection continues for ≈ 8 to 9 weeks in a semester system.

Each student writes a paper in standard scientific format that is due at the end of the semester and also presents an oral report during the final laboratory meeting. Even though written papers are turned in after the oral presentation, plants from each project are sufficient as visual aids to more than adequately illustrate "area effects" to the rest of the class. Oral reports are essential; they are the only mechanism to show the entire class the responses of the species used, especially for growth regulators. In summary, the key points of this project are: a) Choose an unknown plant at random, transplant 20, and work independently; b) place five plants in each of the four areas, wait 1 week; c) treat plants in area III; take initial data measurements in all areas, record light and temperature levels, and continue weekly thereafter; d) identify species to family and genus using specially designed key; e) take one-time data when applicable (e.g., date of first bloom); and f) turn in a written report and make a 10-min presentation to the class at the end of the quarter.

Data analysis

The biggest risk in the development of this project was requiring students to calculate a simple statistic, the standard error of the mean, before making interpretations. This allows the student who is inexperienced in statistics to develop an appreciation for plant uniformity, simple research methods, and the misleading nature of means. An understanding of the standard error has also hastened the grasp of most mean separation tests. But, the class is predominantly sophomores, and virtually none has had exposure to statistics. Computer use proved to be beneficial. Fortunately, Virginia Tech has excellent computer facilities for undergraduates, and many students were computer-literate as incoming freshmen. However, certain laboratories in the early part of the quarter were partially devoted to computer instruction (IBM-PC) for the inexperienced. SuperCalc software was selected because it is available in our computer laboratories, but any spreadsheet product would likely be adaptable. Students were introduced to some specifically created template files for data analysis after practicing useful commands and learning the essence of spreadsheets. A formal lecture explaining standard error and its calculation and interpretation "is also given." Students enter data for each area into the file weekly. The mean, variance, standard error; and upper and lower limits of the mean based on standard error

Table 3. Some responses of recommended species for project use.

<i>Browallia speciosa major</i> (Hort.)—Facultative short-day plant (FSDP), all growth retardants, except ancymidol, were relatively ineffective at rates used. Ancymidol produces obvious greening associated with slightly curled foliage; growth retardation gradually disappears and treated plants may catch up to controls over time.
<i>Calendula officinalis</i> (L.)—Facultative long-day plant (FLDP), plants become significantly elongated under night interruption. Delayed flowering in control area (short days) occurs on relatively compact plants.
<i>Cosmos sulphureus</i> (Cav.) 'Diablo'—A day-neutral (DN) cultivar, although the species is reportedly an obligate short-day plant; grows exceptionally quickly 'Diablo' is not one of the dwarf forms. GA and all the retardants produce temporary effects observed briefly before they resume normal growth. This is an excellent plant for demonstrating low sensitivity to many environmental and chemical modes of manipulation.
<i>Dahlia × hybrida</i> (Cav.)—Dahlia illustrates the widest range of responses. It flowers more quickly under SD, but the most buds occur under LD; plant habit is short and compact under SD and tall and willowy under LD; dwarf cultivars have been used, e.g., 'Rigoletto' and 'Figaro'. At the end of the term, tubers are present on plants from SD while roots remain much more fibrous under LD. The response of dahlias varies with the growth retardant: Ancymidol is the most effective; B9 and CCC less so, but still capable of growth retardation. Apical removal leads to delayed flowering, but increased floral display. Atrinal causes branching, but leaves may show temporary chlorosis.
<i>Eschscholtzia californica</i> (Cham.)—Obligate long-day plant (OLDP); the California poppy will produce significantly more leaves under HID. Growth retardants are applied to plants in SD; hence, they continue rosette growth and will not exhibit reductions in height, only diameter. GA will not substitute for LD consistently, but may cause temporary stem extension in SD with the rosette resuming growth above soil level.
<i>Mimulus luteus</i> (L.)—A FLDP, it flowers sooner and considerably more profusely under night interruption, as well as growing much taller than when the night is not interrupted. It is sensitive to all growth retardants, but responds best to ancymidol, which causes dense foliar greening, reduction in leaf area, severe stem compression, and very undulated leaf margins. This effect is long-lasting. HID lights may enhance leaf area.
<i>Nemesis strumosa</i> (Benth.)—A DN plant, its weak and tall main stem is inhibited by ancymidol. HID lights may cause chlorosis of young seedlings during the first few weeks.
<i>Nicotiana glauca</i> (Link & Otto)—an OLDP, as is California poppy, tobacco illustrates bolting very well. Unlike the poppy, however, GA will substitute for LD; there will be stem elongation and flowering, but the magnitude of both will be less than that caused under night interruption. The 'Nikki' series has been successful.
<i>Rudbeckia hirta</i> (L.)—an OLDP and receptive to HID by producing additional, wider leaves. Some stem elongation occurs with GA under SD, but it is inconsistent and has never stimulated flowering. The cultivars Antique Images and Marmalade are recommended. Flower buds are easily seen even if anthesis does not occur before the end of the semester.
<i>Salvia farinacea</i> (Benth.)—Essentially DN. This plant illustrates the effects of mechanical and chemical pinching very well. Hand-pinching or Atrinal reduces overall height permanently, although Atrinal is more effective. Atrinal also bleaches the newly emergent branches temporarily, but produces a very compact plant.
<i>Solanum melongena</i> (L.)—Although DN, this plant is used for one reason—to demonstrate the damaging effects of ethylene. Following the Florel application, ornamental eggplant becomes stunted via an aborted apex, branching is enhanced, and, most noticeably, leaf tissue deteriorates between the veins. After 3 to 4 weeks, the oldest leaves resemble nets, as if attacked by Japanese beetles. Otherwise, the plant shows very little differential response to the various environmental conditions.
<i>Tagetes erecta</i> (L.)—The common African marigold cultivars prove to be exceptional examples of various responses. It is a FSDP that flowers later, grows taller with upward arching leaves, and branches sparsely under night interruption. Mechanically and chemically pinched plants are shorter, flower later, and possess more flowers than untreated plants. All growth retardants reduce height, but ancymidol is most effective and yields greener leaves than others we used.
<i>Torenia fournieri</i> (Lind.)—Exhibits a slight FSDP response and elongates considerably under night interruption. Its wiry habit is controlled primarily by ancymidol. Atrinal causes temporary chlorosis of the branches along with height retardation, but rampant growth soon returns and may approximate untreated plants.

Table 4. "Bank" of tested species, number of days sown ahead of time when first needed for class (fall quarterly and photoperiod for seedling growth until transplanted for class).

Species	No. days ¹		Photoperiod post-germination ²
	Semester	Quarter	
<i>Browallia speciosa major</i>	14-21	30	LD
<i>Calendula officinalis</i>	7	14-21	SD
<i>Cosmos sulphureus</i>	7	7-10	SD
<i>Dahlia × hybrida</i>	7	21	LD
<i>Eschscholtzia californica</i>	14	21	SD
<i>Mimulus luteus</i>	14	14	SD
<i>Nemesis strumosa</i>	14	21	SD
<i>Nicotiana glauca</i>	14	21	SD
<i>Rudbeckia hirta</i>	21	30	SD
<i>Salvia farinacea</i>	14-21	30	SD
<i>Solanum melongena</i>	14	30	SD
<i>Tagetes erecta</i>	7	14-21	LD
<i>Torenia fournieri</i>	14-21	30	SD

¹It is better to sow—slightly later than earlier if unsure. Younger plants respond better to photoperiod and growth regulator treatments even though the project may end before flowering.

²Because flowering is one of the data measurements, it is important to maintain noninductive conditions following germination.

are then calculated. Greenhouse temperatures are entered as °F, which then are converted to °C; then the light measurement for that area is entered to complete the data sheet.

Computerization has resulted in a significant increase in the quality and standardization of written reports since their inclusion into the laboratory in 1985. The time savings

via their use allows the student to concentrate on the meaning of the data rather than on repetitive calculations and hand-produced, often poor-quality, graphics. Students are always taught, and expected to know, the what and whys of software calculations, even though formulas are embedded within the spreadsheet. The statistically analyzed data are compared to previously published work (Table 5), and students must support or contrast their findings with those in a manual of selected references. *Hort-Science* is almost an exclusive source of these references. Report brevity and use of simple statistics in these readings are easily handled by this heterogeneous class. The reference list is updated each year to remain current and let ambitious students pursue literature citations for additional reading. A few citations have permanent places on the list, despite their early dates of publication (e.g., R. Gray; H.M. Cathey), since they are easily understood and/or describe responses directly relating to the project.

Procedural modifications are possible to suit facilities, personal learning objectives, or simply adapt to unexpected changes. For

Table 5. List of selected readings for students to support/contrast results found in their individual projects.

Supplementary light	
Armitage, A.M. and H.Y. Wetzstein. 1984. Influence of light intensity on flower initiation and differentiation in hybrid geranium. HortScience 19:114-116.	
Downs, R.J. 1985. Irradiance and plant growth in greenhouses during winter. HortScience 20:1125-1127.	
Williams, S., S. Wolf, and E.J. Holcomb. 1983. Growth and flowering of <i>Exacum affine</i> at three radiant energy levels. HortScience 18:366-367.	
Photoperiod	
Bassuk, N. 1986. Year-round production of greenhouse-grown French tarragon. HortScience 21:258-259.	
Hamideh O. and R.N. Payne. 1982. Effects of photoperiod and pinching on development of <i>Begonia</i> $\times$ <i>tuberhybrida</i> . HortScience 17:337-338.	
Haliburton, M.A. and R.N. Payne. 1978. Photoperiod effects on 'Redskin' dahlia pot plants. Oklahoma State Univ., Stillwater. Agr. Expt. Sta. Bul. 735.	
Pinching	
Matta, F.B. 1984. Effects of hand-pinching and dikegulac-sodium sprays on <i>Capsicum annuum</i> . HortScience 19:284-285.	
Nightingale, A. E., S.E. Cross, and M.T. Longnecker. 1985. Dikegulac alters growth and flowering of kalanchoe. HortScience 20:722-724.	
Lyons, R.E. and C.L. Hale. 1987. Comparison of pinching methods on selected species of <i>Columnea</i> , <i>Kalanchoe</i> , and <i>Crassula</i> . HortScience 20:722-724.	
Gibberellin	
Gray, R.A. 1957. Alteration of leaf size and shape and other changes caused by gibberellins in plants. Amer. J. Bot. 44:674-682.	
Evans, M.R. and R.E. Lyons. 1988. Photoperiodic and giberellin-induced growth and flowering responses of <i>Gaillardia</i> $\times$ <i>grandiflora</i> . HortScience 23:584-586.	
Imamura, J.S. and T. Higaki. 1988. Effect of GA ₃ and BA on lateral shoot production on anthurium. HortScience 23:353-354.	
Growth retardants	
Cathey, H.M. 1975. Comparative plant growth-retarding activities of ancymidol with ACPC, phosphon, chlormequat, and SADH on ornamental plant species. HortScience 10:204-216.	
Gianfagna, T.J. and G.J. Wulster. 1986. Growth retardants as an aid to adapting freesia to pot culture. HortScience 21:263-264.	
Holcomb, E.J. 1985. Effect of growth retardants on ivy geranium. HortScience 20:771-772.	
Ethylene	
Tjia, B. and J. Buxton. 1977. Ethrel studies on <i>Petunia hybrida</i> Vilm. Scientia Hort. 7:269-275.	

example, when class enrollment was low, the budget allowed students to photograph plant responses to aid their oral presentations. From my perspective, project completion has had students work independently, analyze and interpret data using simple statistics, enhance their computer-literacy, convey results orally and in written form, and use scientific literature to justify data. Per-

haps the most unexpected benefit is the early identification of talented undergraduates. At least four students subsequently participated in our Undergraduate Research Program, culminating in two refereed papers and one abstract; the fourth used her project as a basis for a MS thesis. Both refereed papers are used in the selected readings list for the project (Table 5; Lyons and Hale, 1987; Evans

and Lyons, 1988).

The course now has a manual with the identification key, essential forms, readings, and discussion of statistics compiled together. It is published locally through a national photocopying chain and purchased directly by students. Changes and updates have been accomplished easily each year.